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OF THE

ELECTRICITY DEPARTMENT

GOVERNMENT OF MADRAS

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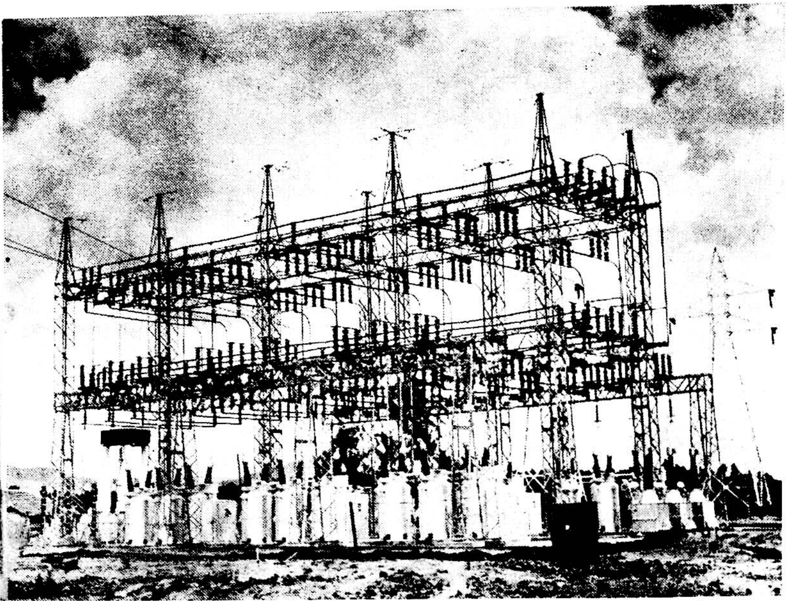

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JOURNAL

OF THE ELECTRICITY DEPARTMENT

GOVERNMENT OF MADRAS

VOL. XI — OCTOBER—DECEMBER 1956 — No. 3

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The Tennessee Valley Authority

*[Extracts from the report of Sri V. P. APPADURAI, B.A., M.I.E. (Ind.), Chief Engineer for Electricity.]**

THE AUTHER WAS DEPUTED by the State Government under the ColomboPlan Fellowship to Canada and the United States of America recently and had the opportunity to visit a number of power systems of the Canadian Electric Supply Undertakings and the Tennessee Valley Authority in the United States. A brief description of the origin and growth of the Tennessee Valley Authority, its power station practices and its organization, is given in this article. Load and frequency control in the Tennessee Valley Authority System: and sub-station, transmission line and protection practices of the Tennessee Valley Authority: will be dealt with in further articles to follow.

THE AUTHOR

I. History and Growth of the Tennessee Valley Authority.

The Tennessee river system in the United States of America drains an area of about 40,910 square miles lying in the Virginia, North Carolina, Georgia, Alabama, Missisippi and Kentucky States. From the highest head water in the mountains in North Carolina to the lowest tail water in the western corner of Kentucky, there is a total fall of 3,188 feet in a run of 714 river miles. Mean annual rainfall on the watershed averages 52 inches and the run-off on the average is 44 per cent.

Till the early thirties, the Tennessee river valley was a scene of vast devastation, caused by heavy cyclonic storms and wide spread floods of the Tennessee and its tributaries. Out of a total of 8½ million acres of cultivable land, nearly 7 million acres had become eroded to different extents. A large part of the land had become old and barren and was in a badly rundown state of cultivation. The river flow varied from a maximum of 500,000 cusecs in 1897 to a minimum of 4,500 cusecs in 1925; and averaged 65,000 cusecs over the period 1889 to 1943. Protection of the valley from the fury of

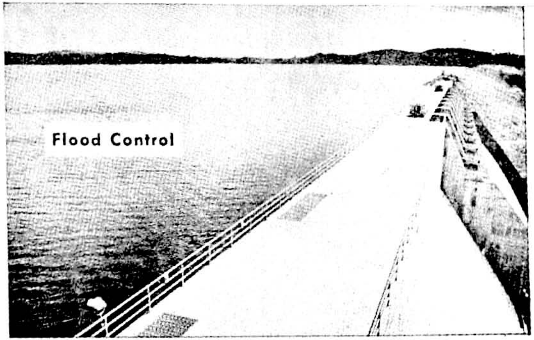
* This article is compiled by Sri S. Raman, Assistant Engineer (Electrical).

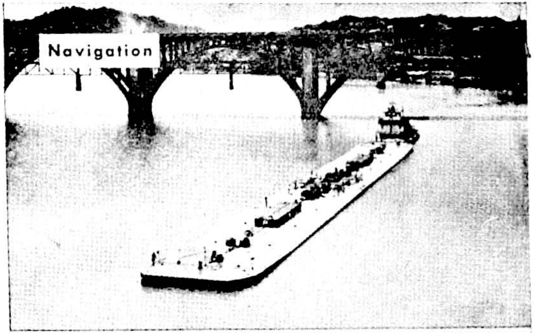
the river was a long-felt want. To afford such protection to the valley and divert the potential strength of the river and its tributaries into useful channels, by its utilization in the production of agricultural and industrial wealth, the Tennessee Valley Authority was brought into existence.

The Tennessee Valley Authority was formed by an Act of Congress on the 18th of May, 1933, with the specific authorization to execute projects, control floods and maintain a 9-foot draft navigation channel from Paducah at the mouth of the Tennessee river to Knoxville. In his message to the Congress, President Roosevelt charged the Tennessee Valley Authority with the broadest duty of "Planning for proper use, conservation and development of the natural resources of the Tennesse river drainage basin and its adjoining territory, for the general, social and economic welfare of the nation". In carrying out this triple objective of planning, conservation and development, the Tennessee Valley Authority adopted a multi-purpose pattern of programme and began to construct a series of dams and reservoirs across the Tennessee river and its tributaries, and operate them for flood control, navigation and power generation. The wandering river got spotted in a short period of two decades by a series of broad and lovely lakes, connected by long channels, that facilitate movement of commercial traffic all along its course, throughout the year; and a chain of inter-connected power stations, facilitating co-ordinated production of large blocks of electric power. The eroded banks were protected by systematised matting, sloping and seeding processes. Utilisation of modern agricultural knowledge, fertilizers, electric power and machinery, helped to change the entire face of the valley into a vast expanse of deep meadows and dense fields of oats and rye, grown high and vigorous with new fertility. The outlook of the valley so much changed with the dams, the lakes, the scenic beauty of the region, forests, parks, fields, fishing and recreation facilities, that they attract more than five million tourists now, in a year. The progress made by the valley in the industrial and electrical fields is equally phenomenal. The progress is so vast that the valley is to-day an important defence arsenal of atomic energy, aluminium and other heavy chemical plants, as well as defence and associated industries. The valley is also to-day, the region of the largest power production in the United States.

By 1952, the Tennessee Valley Authority had constructed eighteen dams—seven on the main river and eleven on the tributaries and acquired nine others. Five more dams, besides were under various stages of construction. The Tennessee Valley Authority dams can now store 15 million acre feet of water, of which 11½ million acre feet of capacity is reserved for flood control. Not only are the floods in the valley effectively reduced; but the control of floods, in the Lower Ohio and Missisippi valleys, is substantially aided.

The system of construction of reservoirs with the multi-purpose object of flood control, navigation and power development, adopted by the Tennessee Valley Authority, was a pioneering attempt in the field of irrigation, navigation and power generation. As flood control is


Flood Control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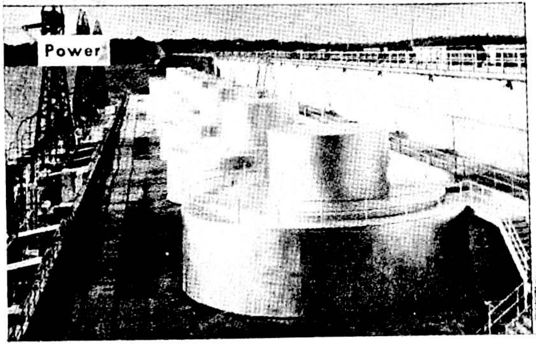
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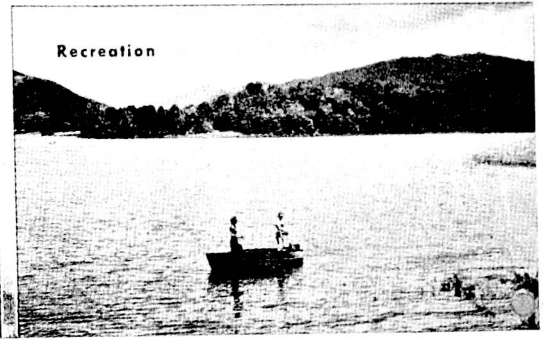
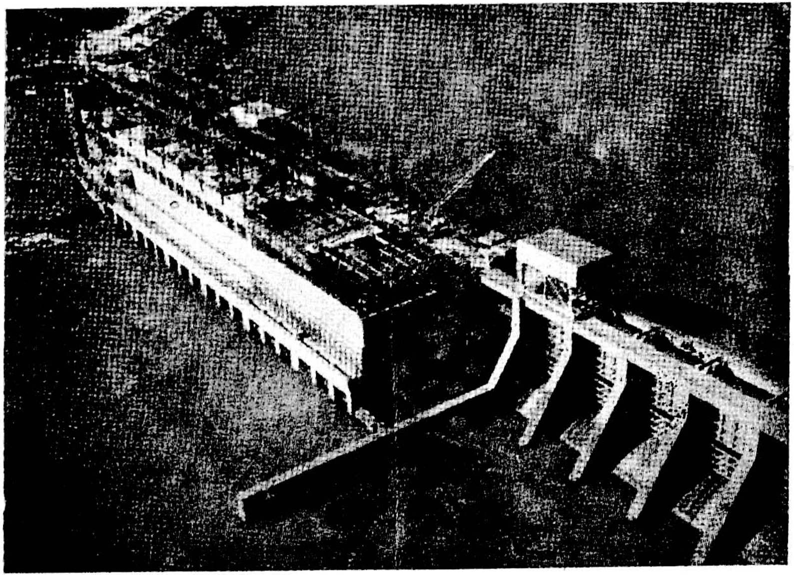

Recreation



‡ Aerial view of the Pickwick dam of the Tennessee valley authority.

given primary importance, the storage in each of the lakes is normally held below a carefully worked out guide curve for each reservoir, to enable sudden floods being regulated confidently; and when a local storm fills the reservoirs above the curves, they are drawn down by spilling or additional generation, and optimum levels maintained.

Of the total costs incurred by the Tennessee Valley Authority in the development of the valley, 65 per cent is allocated to power, 20 per cent to flood control and 15 per cent for navigation.

2. The Tennessee Valley Authority Power System.

2. (1) General.

A map of Tennessee river indicating locations of power stations in its 650 miles stretch, from Fort Loudon to Kentucky, and also its tributaries, with power stations thereon, is given in Sketch I.

All dams, except two, are constructed for both storage and power development. The two reservoirs, Chatuge and Nottely, are constructed solely for storage and have no power stations. In winter and spring, they are operated for flood control and in spring, their storage is drawn down to the Hiwassee Reservoir, for power development.

The Tennessee Valley Authority Power System now includes 32 major dams and power-houses, three modern and four old steam plants and several minor plants. The Tennessee Valley Authority System is integrated with the three hydro-stations of Army Engineers on the Cumberland river; and five hydro-stations of Alcoa on the Little Tennessee river. At Hales Bar, Watts Bar, Wilson and Ocoee-1, both hydro and steam plants are in operation. The generating stations are all inter-connected by means of 8,500 miles of H.V. transmission lines.

Details of hydro dams and power-houses are given in Table 1. Details of the main dams on the Tennessee river are shown schematically in Sketch 2.

Installation capacities of the Tennessee Valley Authority and associated systems, in service, and scheduled to be commissioned, are given below:—

	MW.
T.V.A. hydro station plants, present and scheduled ..	2,635
Provision for additions to above.	75
T.V.A. minor hydro stations ..	22
T.V.A. thermal plants ..	3,144
T.V.A. plants, total ..	5,876
Present stations and planned additions thereto of Alcoa ..	367
Cumberland Projects	595
T.V.A. System, total ..	6,838

2. (2) Type of Plants.

Waterways for the delivery of water to the T.V.A. generating stations fall under three types—

(1) Main river type having a low dam, with the power-house built into the dam and provided usually with a navigation lock.

(2) Tributary type having a high dam, with the power-house close to its base.

(3) Diversion type, having a small diversion dam and a tunnel leading to a remote power-house.

TABLE 1.

DETAILS OF MAJOR TENNESSEE VALLEY AUTHORITY DAMS.

Mame of project. (1)	*Maximum height (feet). (a)* (2)	*Length (feet).* (3)	*Maximum controlled elevation (feet above sea level).* (4)	*Full pool elevation (feet above sea level).* (5)	*Value at maximum controlled eleva tion (acres-feet).* (6)	*Useful controlled storage (acres-feet).* (7)†	*Generating capacity present and scheduled K.W. and number of units ( ).* (8)	*Additional future capacity K.W. and number of units (.* (9)
Main River Projects.								
Kentucky	206	8,422	375	359	6,002,600	4,010,800	160,000 (5)	..
Pickwick landing ..	113	7,715	418	414	1,091,400	418,400	216,000 (6)	..
Wilson	137	4,862	507·88	507·5	562,500	52,500	436,000 (18)	..
Wheeler	72	6,342	556·28	556	1,150,400	347,500	259,200 (8)	..
Guntersville	94	3,979	595·44	595	1,018,700	162,900	97,200 (4)	..
Hales Bar	112	2,315	635	635	154,200	18,900	99,700 (16)	..
Chickamauga	129	5,800	685·44	682·5	705,300	329,400	108,000 (4)	..
Watts Bar	112	2,960	745	741	1,132,000	377,600	150,000 (5)	..
Fort Londown	122	4,190	815	813	386,500	109,300	128,000 (4)	..
Tributary Projects.								
Apalachia	150	1,308	1,280	1,280	58,570	35,730	75,000 (2)	..
Hiwassee	307	1,287	1,526·5	1,526	438,000	364,700	57,600 (1)	57,600 (1)
Chatuge	144	2,850	1,928	1,928	247,800	229,300	..	8,000 (1)
Ocoee No. 1	135	840	837·65	837·65	91,300	33,100	18,000 (5)	..
Ocoee No. 2	30	450	..	..	..	..	19,900 (2)	..
Ocoee No. 3	110	612	1,435	1,435	11,670	7,430	27,000 (1)	..
Blue Ridge	167	1,000	1,691	1,690	200,800	186,300	20,000 (1)	..
Nottely	184	2,300	1,780	1,780	184,400	184,400	..	10,000 (1)
Norris	265	1,860	1,034	1,020	2,567,000	2,281,000	100,800 (2)	..
Fontana	480	2,365	1,710	1,710	1,444,300	1,157,300	202,500 (3)	..
Douglas	202	1,705	1,002	1,002	1,514,100	1,419,700	112,000 (4)	..
Cherokee	175	6,760	1,075	1,075	1,565,400	1,473,100	120,000 (4)	..
Fort Patric Henry ..	95	670	1,263	1,263	29,850	4,600	36,000 (2)	..
Boone	140	1,330	1,385	1,385	211,000	163,500	75,000 (3)	..
South Holston	285	1,600	1,742	1,729	744,000‡	625,200	35,000 (1)	..
Watauga	318	900	1,975	1,959	678,800	627,200	50,000 (2)	..
Great falls	92	800	804·9	804·9	54,500	49,400	31,860 (2)	..

NOTE.—† Useful controlled storage is the volume between the ordinary minimum elevation and maximum controlled elevation.
‡ Two lifts.

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TENNESSEE VALLEY AUTHORITY GENERATING STATIONS.

TABLE 2.

—	*Apalachia.*	*Chickamauga.*	*Fontana.*	*Guntersville.*	*Norris.*	*Wattsbar.*	*Wheeler.*	*Wilson.*	*Kentucky.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1 Drainage area above.	1,018 square miles.	20,790 square miles.	15,715 square miles.	24,450 square miles.	2,912 square miles.	17,310 square miles.	29,590 square miles.	30,750 square miles.	40,200 square miles.
2 Average flow at dam.	2,000 cusecs.	36,500 cusecs.	3,700 cusecs.	42,000 cusecs.	4,100 cusecs.	26,400 cusecs.	49,000 cusecs.	50,500 cusecs.	65,000 cusecs.
3 Head maximum ..	440 feet.	55 feet.	433 feet.	45 feet.	214 feet.	60·5 feet.	52 feet.	96 feet.	73 feet.
4 Average	415 ,,	45 ,,	429 ,,	37 ,,	194 ,,	56 ,,	48 ,,	93 ,,	47 ,,
5 Minimum	385 ,,	3·5 ,,	248 ,,	5 ,,	129 ,,	40 ,,	40 ,,	69 ,,	6 ,,
6 Dam	Non-overflow concrete gravity section. Concrete gravity spillway section.	Concrete spillway section, concrete power house intake section, navigation lock, earth embankment.	Concrete gravity including main spillway.	Concrete gravity spillway section, concrete power-house intake section, navigation lock and earth embankment.	Non-overflow concrete gravity section. Concrete gravity spillway section, earth fill section with concrete core wall.	Concrete gravity spillway section and non-overflow section. Concrete power-house intake section, navigation lock, earth embankment section.	Concrete gravity spillway section. Concrete power-house intake section, navigation lock, non-overflow section.	Concrete gravity spillway section. Concrete power-house intake section. navigation lock, concrete bulk head section.	Concrete gravity spillway section. Concrete power-house intake section. Concrete navigation lock, earth embankment.
7 Length of dam ..	1,308 feet.	5,800 feet.	2,365 feet.	3,979 feet.	1,860 feet.	2,960 feet.	6,342 feet.	4,862 feet.	8,422 feet.
8 Height of dam ..	150 ,,	129 ,,	430 ,,	94 ,,	265 ,,	112 ,,	72 ,,	137 ,,	206 ,,
9 Generating units.	2 × 37,500 KW.	4 × 27,000 KVA.	3 × 67,500	4 × 24,300 K.W.	2 × 50,400 KW.	5 × 30,000 KW.	8 × 32,400 KW.	18 sets of a total of 436,000 KW.	5 × 32,000 KW.
10 Make of turbines.	Baldwin.	Baldwin.	Allis Chalmers.	Margan Smith.	New Port News Ship Building Company.	Baldwin.	Baldwin.	Allis Chalmers I.P. Morris.	Allis Chalmers.
11 Make of generators.	Westinghouse.	Allis Chalmers.	Westinghouse.	G.E.	Westinghouse.	Westinghouse.	G.E.	G.E., Westinghouse and Allis Chalmers.	G.E.
12 Spacing of turbines C.T.C.	44 feet.	80 feet.	56 feet.	78 feet.	60 feet.	73 feet.	76 feet.	55·5 feet.	77·5 feet.
13 Dimensions of the Power house—									
Length ..	147 feet.	426 feet.	205 feet.	406 feet.	205 feet.	470 feet.	868 feet.	1,198 feet.	477·5 feet.
Breadth ..	87 ,,	170 ,,	72 ,,	168 ,,	71 ,,	139 ,,	181·5 ,,	68 ,,	152 ,,
Height ..	98 ,,	170 ,,	127 ,,	166 ,,	125 ,,	133 ,,	125 ,,	134 ,,	151 ,,
14 WR2 of the turbines.	$0·5 \times 10^6$	$6·7 \times 10^6$	$2·72 \times 10^6$	$6·2 \times 10^6$	$2·6 \times 10^6$	$3·61 \times 10^6$	$4·5 \times 10^6$	$2·57 \times 10^6$	$3·15 \times 10^6$
15 Shaft diameter ..	25 inches.	33·5 inches.	34 inches.	35 inches.	35 inches.	32 inches.	33·5 inches.	47·25 inches.	34 inches.
16 Type of guide bearing.	Oil lubricated.	Water lubricated.	Oil lubricated.	Water lubricated.	Oil lubricated.	Water lubricated.	Water lubricated.	Water lubricated.	Water lubricated.
17 Type of Scroll case.	Cast steel.	Concrete.	Plate steel welded.	Concrete.	Plate steel rivetted.	Concrete.	Concrete.	Concrete.	Concrete.
18 Gate servomotors capacity.	7,860	20,300	12,000	14,700	16,900	18,000	24,000	8,400	18,600
19 Blade servomotors capacity.	....	21,200	....	24,400	....	23,600	....	....	30,000
20 Gavernor—									
Make	Woodward.	Woodward.	Allis Chalmers.	Woodward.	Woodward.	Woodward.	Woodward.	Allis Chalmers.	Allis Chalmers.
Type	Cabinet Actuator.	Cabinet Actuator.	Cabinet Actuator.	Cabinet Actuator.	Cabinet Actuator	Actuator Type Cabinet.	Cabinet Actuator.	Cabinet Actuator.	Actuator Cabinet Type.

NOTE.—(*a*) The gate servomotors at all the stations operate at pressures between 250 and 300 lb. per square inch and take a minimum time of six seconds to close.
(*b*) The blade servomotors take a minimum time of eight seconds and a maximum time of 40 seconds to open or close.
(*c*) The draft tube is elbow type for all stations except for Wilson, where it is of Moody Cone type.

The main river type stations are: Wheeler, Pickwick, Guntersville, Chickamauga, Watts Bar, Fort Loudoun, Kentucky and Hales Bar. The river at most of these sites is comparatively wide and shallow. The structures include earth embankments, gravity type concrete dams, broad spillways, short intakes to several generating units and navigation locks. The rated heads range from 35 to 65 feet and propeller type low speed turbines are used. The power-house in each case is built into the toe of the dam as part of the dam structure. The salient features may be seen in the photo of Pickwick dam enclosed.

The tributary type power stations include Norris, Hiwassee, Cherokee, Douglas, Fontana and Boone situated on the tributaries to the Tennesse river, as also the Wilson Project, which, although located on the main river, fits into this classification by virtue of its relatively high head. The river at each of the stations is narrow, and the banks steep; and the structures include concrete type gravity dams, spillways and intakes. The number of generating units in these are less than in the main river type plants. Rated heads range from 90 to 350 feet and Francis type medium speed turbines are used. The power-house in these cases is built close to the toe of the dam as an independent unit.

The diversion type includes the stations at Ocoee. No. 3, Apalachia, Watauga and South Holston. The structure in each case includes a dam, tunnel or power conduit, a surge tank and penstocks. Rated heads range from 180 to 360 feet and Francis type medium speed turbines are used. The power-house is separated from the dam by a distance ranging from a few feet to several miles.

While these three distinct types of development were found needed to meet the natural conditions at various sites, a considerable amount of similarity has been achieved between stations of the same type. Thus Douglas and Cherokee stations are similar and Guntersville and Chickamauga stations are designed with several identical features.

The main river plants are operated continuously, as a rule, to utilize all the available stream flow and the tributary plants are operated to meet both the stream flow conditions and the system transmission requirements.

The tributary plants, including nine built by the Authority and six acquired, are operated on an annual cycle, which provides for filling the reservoirs during the spring and releasing the water during the summer and fall. During the filling season, the generating equipment is operated only to the extent necessary to maintain voltage, or to fill out the capacity requirements during peak load periods, when power available from other sources is inadequate.

The lay-outs of the tributary dams are generally quite simple as navigation facilities are not required to be provided: and the power-house and spillway in consequence, can usually have adjoining locations at the bottom of the valley.

The Tennessee Valley Authority plants, built on the main river have turbines of the propeller type, except at Wheeler hydro-plant, where Kaplan turbines have been installed

with the provision of automatic adjustment of the blade angle to enable operation at the available head, with maximum efficiency.

The steam plants include a modern high pressure plant, built by the Authority at Wattsbar, four old ones, and a number of small standby plants. The old plants operate at relatively low pressures and temperatures and their working is un-economical. However, they are very valuable as standby.

The Wattsbar Steam Plant has four generating units each with a rated capacity of 60 M.W. or a total rated capacity of 240 M.W. Even with present day high fuel costs, this plant produces power at a little over three mils per kWh. exclusive of fixed charges.

2. (3) Layout of Power Stations.

The power houses in the Tennessee Valley Authority Projects are classified into three types, according to their location, relative to the dam :—

Type 1.—The power-house structure functions as a dam. Usually, unit intake and unit structure are integrated into one block to resist water load. There are seven such stations in Tennessee Valley Authority and all have propeller type wheels; and the scroll cases of all of them are of reinforced cement concrete construction.

Type 2.—The power-house is located at the toe of a concrete gravity bulk head with water conduits leading through the dam. In Tennessee Valley Authority practice, there are six stations of this type, using Francis turbines: and all except the Wilson Project have steel scroll cases.

Type 3.—The power-house is entirely removed from the dam. The penstock carries water into the unit substructure. These are also equipped with Francis turbines with steel scroll cases.

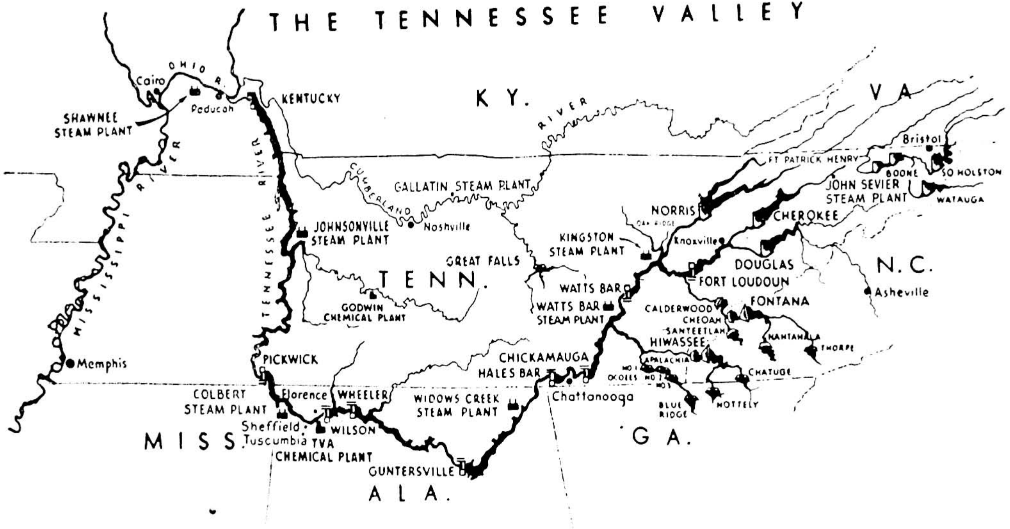
2. (4) Generator Room.

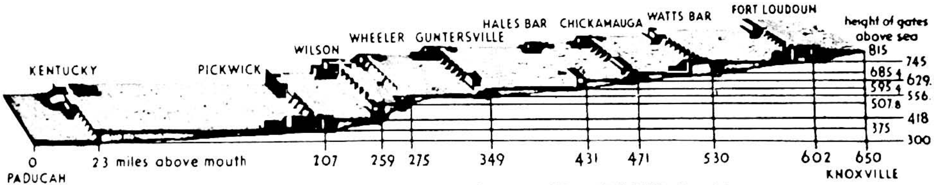
The generator room at Wilson is of conventional construction with high ceiling and indoor crane. The complete structure allows all works on the generating units being carried out, when desired, without regard to weather conditions. The same general pattern is followed in Norris, Pickwick, Guntersville, Chickamauga, Ocoee. No. 3, Apalachia, Fontana, Watauga, South Holston, Halesbar and Fort Patrick Henry power stations.

Wheeler was built without a generator room. The generators extend above the deck of the super-structure and are housed in individual steel housings. They are served by an outdoor gantry crane which travels the full length of the power-house and erection bay, and serves the generating units and assembly areas through roof hatches, which it first uncovers. A gallery below the deck contains the governor actuators, turbine gauge boards and turbine operator's desk.

A design, intermediate between the completely enclosed generator room and total omission of the generator room, referred to as the semi-enclosed generator room, was used at Hiwassee, Wattsbar, Cherokee, Douglas, Fort Loudoun and Kentucky. At these stations a low roof at about crane rail elevation serves also as an outdoor, unloading and working deck.

THE TENNESSEE VALLEY





PROFILE OF THE TENNESSEE RIVER

2. (5) ELECTRICAL BAY.

The electrical bay, housing the auxiliary electrical equipment like the generator main switchgear, breakers for the neutral grounding reactor, excitation breakers and rheostats, fire extinguishing equipment, auxiliary power transformers and distribution boards, etc., is usually located along one side of the generator room, and is so placed as to make the electrical connections as short and direct as possible. In the main river type stations the electrical bay is along the downstream side of the generator room over the draft tube. In some of the tributary plants, it is in the triangular section between the dam and the power-house.

The Tennessee Valley Authority have made every effort to specify for all their generating auxiliary equipments, characteristics and construction which are fairly well standardised by all the manufacturers so as not to demand special features.

2. (6) TRANSFORMERS.

In many Tenneessee Valley Authority stations, there are two transmission voltages. The generator voltage is in some cases, stepped up by means of three-winding transformers to two voltage levels. In others the voltage is stepped up by double-wound transformers to the voltage level that carries most of the power output, and smaller transformers are used for transformation of that voltage to the second level. In either case, automatic voltage regulation is provided for one of the system voltages and for the other, the regulation is by the generators, only.

2. (7) AUXILIARY SUPPLY.

Auxiliary power at 400 volts is normally supplied from the main generator through duplicate 1,000 KVA. transformers connected to the generator leads through motor operated disconnecting switches.

A rural line of sub-transmission voltage, from a neighbouring generating station or sub-station, supplies a small emergency station service transformer.

Also a 300 K.V.A. gasoline engine-driven generator furnishes emergency power to operate essential auxiliaries, such as spillway gates, the navigation lock, the pumps and the station lights, in the very rare event of complete shutdown of all the generators and loss of supply from all transmission line connections.

Step-down transformers connected to main step-up transformers are also used to supply the auxiliary power in some stations.

The table below gives an indication of actual connected loads and measured demands, taken from four typical stations—

Stations.	Kentucky.	Fort Loudoun.	Fontana.	Apalachia.
1 Type of development ..	Main river.	Main river.	Tributary.	Diversion.
2 Station capacity in K.V.A.	175,000 in 5 units.	142,200 in 4 units.	225,000 in 3 units.	80,000 in 2 units.
3 Motors—				
Number	126	105	68	55
H.P.	2,511	1,789	1,096	566

Station.	Kentucky.	Fort Loudoun.	Fountans	Apalachia.
4 Heating—				
Number	53	49	45	30
K.W.	888	722	771	351
5 Lighting—				
Transformers K.W. ..	395	388	386	205
Lighting K.W.	301	216	270	113
6 Total connected load in K.V.A.	3,810	2,520	2,140	1,038
7 Measured demand K.V.A.	1,010	766	563	252·
8 Measured P.F.	0·74	0·75	0·81	0·84
9 Transformer capacity K.V.A.	1,250	1,000	1,000	450

2. (8) Auxiliaries.

A 250 volts 50 amps 8 hour: and 480 amps 1 minute storage battery with two 130 KW. motor generator charging sets are provided for control operation, emergency lighting system and standard frequency motor generator set. Automatic synchronizing equipment is provided. This includes speed matches with suitable protective features to prevent closing of control circuit except under correct synchronising conditions.

A 60 cycle tuning fork with amplifiers provide an accurately controlled frequency source of limited output for operating the station frequency controlling equipment, time error indicator, master frequency clock, recorders, etc.

2. (9) Control Room.

The control room location, considered most suited, is in the service bay or electrical bay, where it would be central between the controlled equipment in the power-house and the switchyard. It is generally considered more important to provide a short direct route from the control room to the switch yard to facilitate the control operators to patrol the switchyard and operate disconnecting switches, etc. It is also found preferable to route the control cables and conduits from the control room to the power-house in one direction and to the switchyard in the opposite direction.

The Tennessee Valley Authority practice is to make the control room as nearly sound proof and vibrationless as possible. The control room is also air conditioned to ensure accurate readings of the instruments.

For routing of the cables connecting the units and switch-board to their proper boards in the control room, a spreading room about the same size as the control room is provided immediately below the control room. These cables are carried in trays and pass upward through slots in the floor. In smaller stations, the trays may be suspended from the ceiling with the floor below assigned to other uses. In larger stations, the room is assigned exclusively for cable spreading.

In Tennessee Valley Authority practice, cables connected to the unit blocks are carried on trays in a cables gallery, while for connection with the switch-yard, either trays in the cable tunnel or buried conduits in duct lines are used.

2. (10) SCHEME OF SWITCHING AND CONNECTIONS.

The simplest scheme is to connect each generator through its individual two-winding three-phase transformer or bank of three single phase transformers to a single high voltage system, with no direct load on generator except station service. This scheme is adopted at Norris, Pickwick, Wattsbar and other plants. Synchronizing is done on the high voltage breakers. A motor operated disconnect, electrically interlocked with the transformer high voltage breaker, is provided in the main circuit of each generator for purposes of isolating and testing, when needed.

As the power system expanded, it was found that outage of two generators in the rare event of transformer trouble could be tolerated, and economy was effected by connecting two generators per transformer bank in stations like Wheeler, Wilson, Cherokee, Douglas, Fort Loudoun and Halesbar.

Circuit breakers are provided for each generator to facilitate synchronizing and to enable switching on or off to suit changes in station load.

With respect to the auxiliary power supply at each station, the switching arrangements permit operating the entire system on either of the two power transformers, normally provided, for the purpose of dividing it between the two. Automatic switching from one source to the other in case of loss of voltage is not considered desirable for an attended station, because the momentary loss of auxiliaries does not ordinarily shut down a unit or cause shedding of load. For unattended stations, transfer of loads from one source of supply to the other in case of loss of voltage is accomplished automatically.

If a load is to be changed over from one source to another in an attended station, the load is always disconnected from the one and reconnected to the other, so as to avoid parallelling of the two sources. The momentary interruption caused thereby is considered acceptable rather than risk the possibility of a surge resulting from the parallelling of the two sources of supply.

2. (11) GENERATOR CHARACTERISTICS.

Table 2 gives the technical characteristics of the turbines and generators installed at nine of the main generating stations of the Tennessee Valley Authority at Apalachia, Chickamauga, Fontana, Guntersville, Norris, Kentucky, Wattsbar, Wheeler and Wilson.

The principal features of the generating machinery for the generators installed up to 1953 are briefly as follows :—

1 Power factor ..	0·9
2 Short circut ratio.	1·1
3 Condenser capacity (over excited) ..	55 per cent.
4 Line charging capacity (under excited) ..	80 per cent.
5 Non-continuous damper winding giving a ratio for subtransient reactance quadrature, to subtransient reactance direct, of	1·35

6 Fly wheel effect based on 30 per cent speed rise with full load rejection and gate closure in 5 seconds resulting in 120 to 180 per cent of normal fly wheel effect.

7 Excitation voltage .. .. 250 volts.

8 Ceiling voltage. 325 volts,

9 Response ratio. 1

10 Direct connected main exciter and pilot exciter partially telescoped.

11 Thrust bearings below the rotor usually are guide bearings also below the rotor.

12 CO_2 fire protection for the generator.

Other characteristics are given in the table appended.

2. (12) Special Features.

Certain special features of a few Tennessee Valley Authority stations are given below :—

Hales Bar Station.—The Hales Bar hydro plant, one of the two river projects, acquired by the Tennessese Valley Authority was constructed 35 years ago, at a time, when low head turbines of large sizes were not available; and it was found necessary to have three water wheels mounted on a single shaft, to obtain a small output of 3,500 K.W. per unit at the rated head or 36 feet. Fourteen such units were installed to obtain a total capacity of 50 M.W.

Wilson Station.—The Wilson plant was the second main river project, acquired by Tennessee Valley Authority. It has a length of 1,200 feet. This is easily the longest Tennessee Valley Authority power station at present. The station had 8 units at the time, the Tennessee Valley Authority took over: and 6 units have since been installed by the Authority making the total capacity 352 M.W. Four more units are planned to be commissioned, making the total installed capacity 436 M.W.

Ocoee-No. 3-Station.—Ocoee No. 3 station is one of the two tunnel stations of the Tennessee Valley Authority. The tunnel is constructed close to the minimum hydraulic gradient up to a suitable point above the power-house and from there the water is conducted to the generating units, through exposed steel penstocks.

The power station is fed by a tunnel 13,000 feet long, of which a length of 12,500 feet is of 12½ feet horse-shoe section, fully lined, the remaining 500 feet being of steel-lined circular section. The tunnel carries about 1,200 cusecs of water to operate the plant under 313 feet head. The surge tank is of steel 40 feet in diameter and 142 feet high, resting upon a rock foundation, a short distance above the tunnel. The penstock details are as under :—

Diameter	..	11 feet.
Area ..	..	95 square feet.
Velocity—		
Normal	..	12·7 feet per second.
Maximum	..	16·4 feet per second.
Discharge—		
Normal	..	1,200 cusces
Maximum	..	1,550 cusces

Apalachia.—Apalachia is the second tunnel project of the Tennessee Valley Authority with an average head of 415 feet and a maximum head of 440 feet. The tunnel consists of 35,600 feet of 18 feet diameter lined tunnel, 6,000 feet of unlined tunnel and 200 feet length of 16 feet and 18 feet steel

penstocks. Maximum discharge through the tunnel is 3,200 cusecs giving a velocity of 13 feet per second in the concrete portion.

The details of penstocks are as under :—

Diameter	..	11 feet.
Area ..	..	95 square feet.
Discharge—		
Normal ..	..	1,500 cusecs.
Maximum	..	1,850 cusecs.
Velocity—		
Normal ..	..	15·8 feet per second.
Maximum	..	19·5 feet per second.

With such a large discharge, and so long a tunnel a large surge tank was necessary and the tunnel alignment was fixed such that this tank could be constructed by excavating it on the top of the hill, adjoining the power-house. The surge tank is 235 feet deep, 66 feet in diameter and of the Johnson differential type. It has a steel riser 16 feet in diameter and extending 214 feet above the bottom of the tank.

3. Development Programme of the Tennessee Valley Authority.

The Tennessee Valley Authority power extends practically to all of Tennessee, Northern Alabama, North-eastern Mississippi and South-western Kentucky States and parts of Georgia, North Carolina and Virginia States covering an area of 80,000 square miles with a population of five million. About 2,800 industrial concerns in the area are supplied by the Tennessee Valley Authority. The units generated in the T.V.A. power houses, in 1952, were 19·7 billion.

Apart from meeting the growing needs of chemical and metallurgical industries and agriculture in the area, the T.V.A. has been called upon to meet the Atomic Energy Commission's requirements at Oak Ridge, and Paducah and an Air Force Wind-tunnel project at Tullahoma, Tennessee by 1955. The requirements of the Atomic Energy Commission alone are estimated at 25 billion units per annum. Energy requirements of the area are expected to rise to 60 billion units that is, three times the present generation, in the year 1956. To meet the vast anticipated growth of load, the Tennessee Valley Authority is now building five hydro stations totalling 500 M.W. and seven large steam plants are also being built as under :—

Location.	M.W.
Johnson Ville	675
Widows Creek	675
Kingston	1,260
Shawnee	1,350
Colbert	720
Gallatin	450
Johnsevir	360

The Cumberland projects of the Army Engineers were also expected to be augmented by 287 M.W. by 1956–57. The total capacity of the Tennessee Valley Authority System was expected to reach 10,000 M.W. in 1956.

The generation, integrated by the system, of 19·7 million units in 1952 was made up as under :—

Details.		Billion units.
T.V.A. hydro plants	..	12·2
T.V.A. thermal plants	..	4·3
Alcoa plants	.. ..	1·8
Cumberland plants	..	1·4

The financial results of the T.V.A. Scheme were as under in 1952 :—

Capital outlay	..	555 Million dollars.
Net income	..	26 Million dollars.
Return ..	..	4·7 per cent

Over 19 years of T.V.A's existence, the return averaged 4·25 per cent. The Government borrowed money at 2 per cent during this period.

4. Organisational Set-up.

The Tennesse Valley Authority Power System is one of the most complex in existence, from the standpoint of the number of plants and lines, number of inter-connections with other utilities, magnitude of power flow on inter-connecting lines between plants, and the fluctuations of power flows, with the constantly changing water and load conditions from one end of the system to the other. The Tennessee Valley Authority System inter-connects with the transmission and generation facilities of eight utility concerns, one Government hydro-electric plant and the large manufacturing company of Messrs. Alcoa through large capacity transmission lines. A group of specially trained engineers keep continuous contact with the changing system characteristics and load requirements and decide on the operational changes that are to be effected from time to time.

The Power Department of the Tennessee Valley Authority consists of the following Divisions :—

1 Division of Supply.

2 Division of Power Operation.

3 Division of Power Utilization.

4 Division of Power Engineering and Construction.

The Division of Power Operation under the control of a Director of Power Operation is responsible for the operation and maintenance of the Tennessee Valley Authority Power System. The Director is assisted by the Power Production Branch, Power System Operations Branch, Power System Service Shops Branch, Transmission System Maintenance Branch, and the Electrical Laboratory and Test Branch.

The Power Production Branch is responsible for the operation and maintenance of all hydro and steam generating plants. The Chief of the Branch is assisted by two Principal Assistants, one for hydro and the other for steam plants. The Hydro Assistant Chief keeps in touch with the Power Plant Superintendents of each plant, co-ordinates maintenance schedules, and renders advice on operation and maintenance problems. The Steam Assistant Chief has similar responsibilities in connection with operation and maintenance of steam plants.

He is assisted in his work by Power Plant Superintendents responsible to each plant or a group of plants; and a Results Engineer, who is responsible for continuous review of the performance of the plants and effecting such changes in operation practices and control equipments, as to enable the boilers and turbines to operate at best pos ible efficiency.

The Power System Service Shops Branch is in charge of a Chief of Branch, assisted by a Chief Electrician and a Master Mechanic. There is a large machine shop, equipped to handle all mechanical repair work and an electrical repair shop, that can handle major repairs on power transformers, circuit breakers, motors and other equipments.

The Power System Operations Branch is responsible for proper co-ordination of the operation of power system and water control facilities for the operation of all attended sub-stations and for conducting technical studies and investigations required for the operation of the system. The Branch has four sections, viz. (i) Statistical and Power-supply; (ii) Sub-Stations; (iii) Relay and Protection; and (iv) Load Dispatching. Loading schedules and settings on the line-load regulating equipments are prepared by the Statistical and Power-supply section and any changes therein are directed by the Power System Dispatchers to ensure efficient operation of the system. During emergency conditions, the Power System Dispatchers direct all switching operations necessary to restore service and to isolate faulty equipment. Water regulation is in accordance with instructions issued from time to time by a separate "Division of Water Control Planning", in accordance with the "Statistical and Power Supply" section.

The Electrical Laboratory and Test Branch is responsible for electrical and chemical testing, maintenance of meters and metering equipments on the entire system and maintenance of carrier current and other electronic equipments. This Branch reviews and recommends plans and designs relating to metering, relaying and control instruments and all communication and signalling facilities. These activities are directed by the Chief of the Branch, with the aid of one Principal Assistant, one Special Engineer, and an 'Administrative Service Unit'. The Branch is composed of a Technical Staff section, a Communication section, a Laboratories and Shop section and three Field Sections.

The Transmission System maintenance section is responsible for general supervision and co-ordination of maintenance of transmission lines and sub-station equipments. This section is responsible for inspection of all power and communication poles. There are more than 75,000 poles requiring inspection every three years (i.e.), there are 25,000 to be inspected per annum. This section studies and investigates all accidents. It inspects all new lines and passes, final acceptance for operation. It keeps a record of all tests on equipment-oils and recommends change or reconditioning before deterioration. A number of sub-station maintenance supervisors assist the Chief in carrying out the work.

5. Pattern of Unified Development.

The influence of the Tennessee Valley Authority pattern of development has been felt world wide. The Tennessee Valley Authority conception of regarding the whole river basin as a unit, applying unified control and development by multipurpose dams to the entire river and its water shed ; and gradual but decisive improvement of the valley resources to the highest level of prosperity, has been accepted worthy of emulation by engineers all over the world. As many as 18 river valley projects, including the Damodar Valley Project in our country have been based on the example of the Tennessee Valley Authority ; and the experience of the Tennessee Valley Authority has been acknowledged valuable in the conception and execution of these projects. The process of mutual assistance through integration of power with other supply systems also found favourable response with other federal agencies of the United States in promoting co-operation with each other in the unified development of the resources of each area, considering the economic prosperity of the region as a whole, and discarding unrelated and haphazard improvements.

6. Conclusion.

With more than 40 power stations and 8,500 miles of interconnected transmission lines, centralization of control of individual power stations with respect to the varying hydro conditions, maintenance of reservoir levels within predetermined schedules, and maintenance of required power interchange between tie-lines, is by no means an easy task. The Tennessee Valley Authority however has succeeded in achieving this by installing load and frequency control equipments at a number of stations, that automatically control generating units of a station, so as to accomplish any one of the conditions of operation that may be considered necessary like, holding on each unit a fixed load ; maintaining a fixed station output ; permitting load changes on the units for absorption of load variations in an area ; maintaining selected tie-line load ; and also allowing one or more generators to operate as synchronons motors in case of tie-line failure, with control to pick up load on the resumption of the tie-line supply. How this control is effected would be dealt with in a separate article.

Corrosion in the Battery Plate Group Bar Connections.

By P. R. NARASIMHAN, B.E.,
Divisional Engineer (Electrical).

THIS Article covers the experience of the Author in the maintenance of storage battery in a power house and deals with certain particular defects noticed and remedial measures taken to maintain the battery in service condition.

THE AUTHOR

Corrosion in group bars.

The group bars and the lugs of the battery plates of lead acid open type cells were all in titially painted with anti-sulphuric paint, red and black, during installation. However, after about 3to 4 years' service, it was found that in some cells the painted surfaces had flaked and in others abnormal growth of the plates lugs and the group bars had been noticed. On scraping off, the flaked paint was found to come off dry in some cells, while in others it was found to be wet and to have a white coating beneath, over the group bars. Prabably a white priming coat had been given first. When the paint in the group bars, which had bulged was scraped, the paint came off in thick flakes leaving a thin wet white coating over the group bars. The group bars had also some pittings and had become thin due to corrosive action, especially at the junction of the lugs to the group bars. It was suspected that the anti-sulphuric paint used was not good and had the deleterious effects stated above. So, these were completely removed in the affected cells, and the surfaces cleaned thoroughly dry and coated with white vaselene.

After some time, further trouble of a serious nature occurred in some of the remaining cells, which looked alright outwardly with no flaking of paint or protruding growths. During routine inspection some small hair line cracks in the paint was noticed at the junction of the positive plate lugs and group bars on the top surface and also on the sides and these positive plates were also not healthy. A pin was poked into the junction of the lug and the group bar and it went in right through at the junction, indicating thereby that the metal had got replaced by some soft material. It was surprising to see on further examination that even a small thin splinter could be moved up, and down, right across the junction of

the lugs and the group bars, thus indicating complete deterioration of the joint and the positive plate having no effective connection at all with the group bars. The group bars by themselves were held in position by a few other lugs, which were not so much deteriorated and also by the adjacent group bar connections. The deteriorated stuff at the junction of the group bars and the lug was a wet brown substance. The deterioration is probably due to the presence of impurities in the lugs of the positive plates at the portions, where they are cut and burnt to the group bars vide Fig. 1. Such corrosion in some cells was so much that the group bars got detached from the plates on touching. In the broken edges of the lugs and the cross bar, small thin streaks or small specks of dull lead were noticed at the group bars and the lugs' ends. So, a situation presented itself that amounted to, or at any time may result in, an open circuit of the storage battery, intended for the control circuits in a power house, with all the consequences that follow such a contingency.

Rectification works

Immediate rectification of the much affected cells to bring them into circuit was imperative, as there were no spare cells or plates. As already stated, there was only a thin streak of metal in the cut edge of the positive plate lugs. The rest of the portions had all become black and oxidised, and when this was scraped off a very thin perforated lead sheet only was found sticking to the positive plate proper. The connection was so thin that these positive plates could get even detached from the group bars and fall into the cell as there was no strong supporting lug to rest on the cell edges. The possibility of lead burning the existing plate lugs to the group bars was ruled out. The only remedy was to build up the new lugs from positive plates ends themselves or from such portions of the lugs which are good and thick enough and then burn the lugs to the group bars. The defect was present in almost all the cells to varying extents and all the cells required immediate attention and rectification.

In addition to the above defect, viz., corrosion at the junction of the positive plates' lug to the group bars there was also another defect noticed in the negative plates of each cell but it was not so serious as to put the battery out of service. The defect in the negative plates was that the seam was split up to varying extents on all the four edges, and there was the possibility of the active material falling off, although the active material is kept pasted inside the plate box.

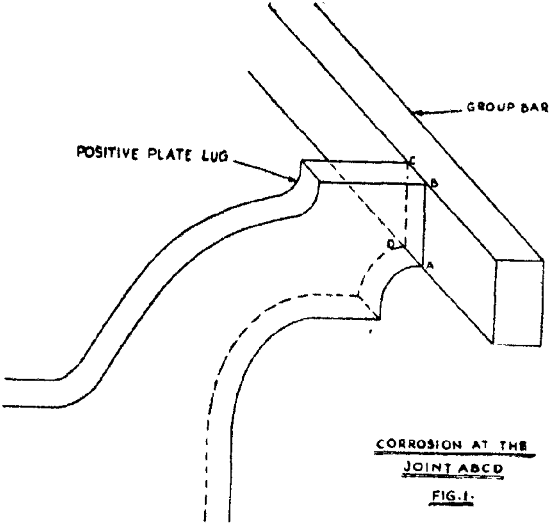
So, the rectification works in each cell comprised of :

(1) Removing the buckling of the positive plates, wherever present.

(2) Building up of the positive plate lugs.

(3) Burning of the positive plate lugs to the group bars in the correct position.

(4) Pressing together the split edges of the negative plates and welding them to the required length and spot welding at regular intervals in other locations all round the edges, so that further splitting of the same does not occur.



CORROSION AT THE JOINT ABCD

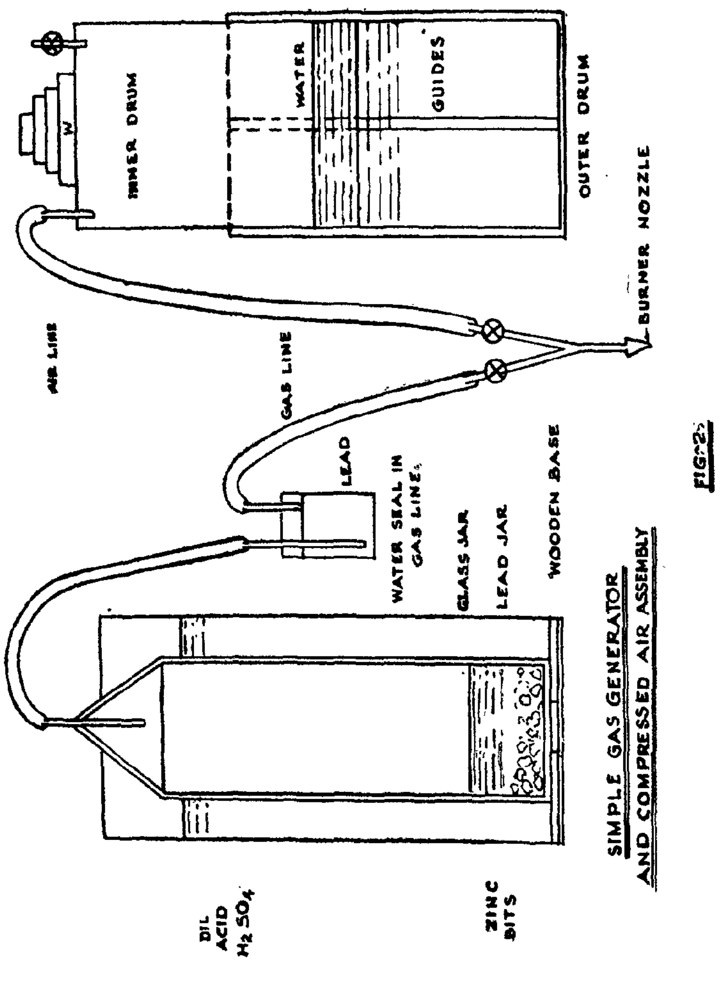
FIG. 1.

(5) Assembling the cells and putting them to a few cycles of charge and discharge. and commistioning.

The work of lead burning, especially the very thin sheets of the negative plates requires much skill and the use of a hydrogen flame was preferred for the entire work. A hydrogen gas out-fit had to be built up to take up this rectification work.

Set-up of Hydrogen generator.

As no sufficient size lead sheet was available, the lead sheath from old discorded cable bits were removed. They were only about four inches wide. As such they were all put together and patched by Oxy-acetelyne flame, and a made up lead sheet of about 20 inches into 24 inches and about 1/8th inch thick was obtained. This was then rolled into a cylinder with a conical end vide Fig. 2, A spout for taking off the gas was introduced and all joints were made gas tight. All the joints above the acid level in the gas generator was made with ordinary tin solder and this soldering was limited to the minimum. The battery cell glass jar itself was utilised as the outer container for the gas generator and this helped in noting down the level of acid within A small water seal gas trap was prepared and introduced into the gas line, so that the hydrogen flame was



SIMPLE GAS GENERATOR AND COMPRESSED AIR ASSEMBLY

FIG-2

not in direct communication with the main gas cylinder. A simple compressed air receiver was rigged up as shown in Fig. 2 and this facilitated to regulate the air pressure by adjusting the weight on the air cylinder. A small nipple from a gas welding tool kit was made use of for rigging up a burner to get the required flame jet, the air and gas being regulated by the two control cocks. Tough rubber tubing was used for both the gas and air lines.

Starting of hydrogen generator.

Small broken pieces of commercial zinc are placed inside the lead jar of the generator and dilute sulphuric acid introduced inside the glass container to less than half its depth After two or three minutes the gas line is closed. The hydrogen gas generated fills up the inner cylinder and pressure rises up as noticed by the level of electrolyte in the glass cantainer. The air line is then connected up to the burner. The gas and air lines are then opened and a flame through the nozzle is struck. The quantity of gas and pressure of air are then adjusted to get the required size of flame and tested by burning small lead pieces. The gas generator is now ready for service. During working, the generation of gas slows down and its pressure begins to fall after some time due to the formation of sulphate over the zinc pieces. As such to keep generation even, periodical shaking of the zinc pieces or their renewal is necessary. Similarly the air feed and air pressure will also fall gradually and it will be necessary to go on adding weights over the inner drum to get the desired pressure and ultimately this inner drum has to be emptied of the water and re-introduced with weight on top. These two items are to be periodically attended to in the course of a day's work, depending upon the duty, the generator is required to perform.

Repair work on the Battery plates.

The buckling in the positive plates was removed, as usual, in the wooden press. The lugs were then well cleaned of all black stuff till the lead portion was clearly seen. The cleaned lugs were of irregular shape and thin. They were then cut square at the end for burning new lugs. Thin zinc sheet strips were clipped on to the positive plate lug bits suitably, and these were then bent to shape to form a mould so as to get the desired size and thickness of the lugs, when lead was filled in this mould. This moulding was adopted, when the portion to be made up in the lugs was not much. The filling up was done by fusing fresh lead with the hydrogen flame. However, in some plates the corrosion was so much that there was practically very little lead portion left over in the lugs and new lugs had to be formed right from the plate ends. In such cases, the lugs were pre-moulded and then fused in position with the plates. Lead salvaged from the discarded battery plates was used in the formation of lugs, group bars and also for fusing.

The plates thus got ready were assembled in the wooden press in proper alignment, so that the bottoms of the lugs were all at the same level. Then the group bar was held in the correct disposition to the plate lugs, and the lugs were burned well to the group bar to

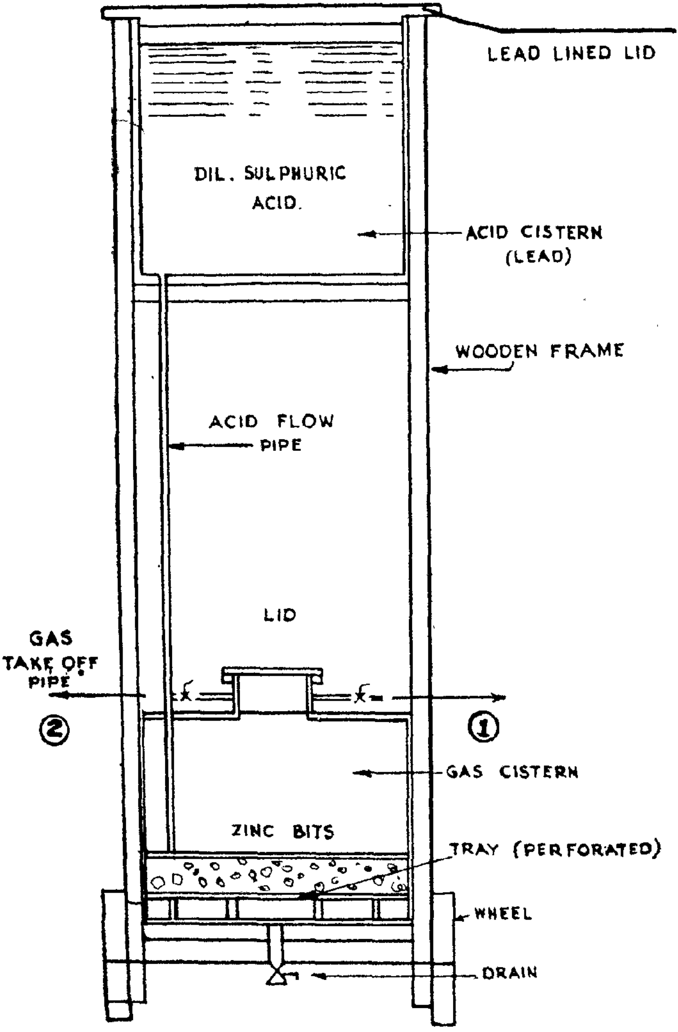


FIG. 3. A BIGGER GAS GENERATING UNIT

sufficient thickness alround. The positive plate set was thus got ready.

The split edges of the negative plates were nipped together by a plier and the pressed seams welded to the required length, using thin lead strips and a very thin narrow flame. In addition spot welding at regular intervals all along the seam edges of the negative plates was done to prevent further splitting. Spot welding of seam edges required much skill as the plates were very thin and liable to be burnt off leaving a puncture in the plate.

It was found that only one person was able to work on this simple hydrogen generator and the capacity also was not sufficient for continuous work with sufficient pressure. So the work of reconditioning all the 60 cells would have taken a long time, whereas the reconditioning had to be done as quickly as possible. So, a bigger gas generator, which can give good pressure of gas as well as allow two persons to work thereon, one on the positive plates and the other on the negative plates, was found necessary to maintain progress, and such a unit as shown in Fig. 3 was rigged upon the same principle as the smaller one. The bigger unit had the advantage of giving good pressure hydrogen and also when the hydrogen take off was not much the acid rose up fully to the top chamber thereby discontinuing generation when not required. Further two persons were able to work together and this speeded up the rectification work to a great extent.

Conclusion

The positive and negative plate sets, thus got ready, were assembled, and the cells were then put on a few cycles of charge and discharge and commissioned. The battery set has since been giving satisfactory service, and there has been no recurrence of corrosion troubles, at the group bar connections.

Whole Range KVAH Meters

By S. RAMAN, B.E. (Hons.),
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Introduction.

In a previous article on "Limited range KVAH meters,"* a short reference was made by the Author to the principles of working of the different types of compensated KVAH meters, and the accuracy of registration, that may be expected in them. These meters are reliable only within the limits of power factor range marked on them; and even within this range, there is a small error in registration that may not normally exceed 2 per cent of true value. They are useful for small installations, where the range of power factor variation under load is not much and a general watch on overall and peak-load power factor is deemed sufficient for practical purposes In this article, the limitations to be kept in mind in the use of these meters are further dealt with and the principles of KVAH meters that are suited to any working power factor of load and any variation thereof, briefly described.

Utility of compensated KVAH meters.

Principle of operation.—In a compensated KVAH meter the potential flux shunted to the disc lags the series flux by an angle greater than 90 degrees, say $90 + m$ unlike a KWH meter, where the angle of lag is exactly 90 degrees at U.P.F. of load. In consequence, when load power factor is cos m lag, the meter records maximum of $\sqrt{3}$ EI as a KWH meter does for unity power factor. When the load power factor is cos $(m-\theta)$ the KVAH meter registers $\sqrt{3}$ EI cos θ which is the record of a KWH meter at a power factor of cos θ. The variation in registration follows the variation of load power factor with an angular lag in the power factor equal to m. As the registration of the KVAH meter is a cosine function, any departure from the mid-power factor angle 'm', for which the meter records maximum, results in an error in the registration of KVAH units, and a large departure will result in a large error in such registration. However as—

Cos.	11°	0·98,
Cos.	14°	0·97,
Cos.	16°	0·96,
& Cos.	18°	0·95,

for a meter, correctly compensated at mid-power factor, a change in the power factor angle from the mid-power factor, of 11°, 14°, 16° and 18° on either side can produce

* The author is grateful to Sri V. K. Sethuraman, B.A., A.M.I.E. and Sri D. V. Subramanyam, B.SC., for their valuable criticism on this previous article, which has been incorporated in the present article.

an error in registration of only 2 per cent, 3 per cent, 4 per cent and 5 per cent respectively. If a variation of 16 degrees is permitted on either side of the mid-power factor, there would be an overall error of 4 per cent in the registration of the KVAH units at the extreme limits of power factor with respect to the registration at mid-power factor. It is usual in this case to adjust the meter 2 per cent fast at mid-power factor, when it would record 2 per cent slow at the limits of power factors permissble for the meter.

Taking the limits of power factor for a particular installation meter as 0·7and0·95 lag, the corresponding, power factor angles are 45° 34' and 18° 12'; and the mid-power factor angle is 31° 53' corresponding to a power factor of nearly 0·85. The range of variation of power factor angle on either side of the mid-power factor is 13° 41', corresponding to registration of Cos. 13° 41' or 97 per cent of actual units. The meter, in this case, has an overall error of 3 per cent only from mid-power factor of 0·85 to the extreme power factors of 0·7 and 0·95. The meter would be adjusted 1·5 per cent fast at mid-power factor, when it would automatically record 1·5 per cent slow at 0·7 and 0·95 power factors.

Deficiencies in the use of the meter.

The deficiencies in the use of meter are as under :—

(a) *Limited range of power factor.*—The variation of 1·5 per cent or 2 per cent of true value, in the record of KVAH units, and KVA demand ; a plus error at mid-power factor and a minus error at extreme power factors, amounting to a total variation from mid-power factor registration of 3 per cent or 4 per cent over the working range, is an inherent characteristic of the meter. As Indian Electricity Rules, 1956, permit an error in registration of 3 per cent only for these meters there is just 1·5 or one per cent range alone, available for the meter error and the variation in registration of meter during service. As at least a range of one per cent is necessary to be provided for the meter error and service variation of the meter, any inherent error exceeding 2 per cent is not desirable ; the calibration should therefore be restricted to an error of 2 per cent up or down ; and to this extent, the range of variation of power factor, during which the meter may work, is to be limited to an angle of 16 degrees on either side of the mid-power factor angle, so as to ensure that the meter records during service within the permissible limits of 3 per cent error in registration. It is not advisable to have a range of variation for the working of the meter as much as, 20 degrees on either side of the mid-power factor angle and to have all the 3 per cent permissible variation, as an inherent error in the meter itself. A meter of such wide range would have to be considered, as not complying with the Indian Electricity Rules.

(b) *Average power factor at the installation.*—Normally, the average power factor at an installation during a period can be inferred from the units registered by the KVAH and KWH meters. Where load is less and power factor is poor, the compensated KVAH meters registers more than the KWH

meter, but its registration is far less than the actual KVAH units, as the meter would then be working beyond its utility range. Continuous integration by the meter under low load conditions would therefore be deficient, and a review of the units registered by the KVAH meter, on comparison with units, recorded by KWH meter, would indicate a somewhat better power factor for the load, than what is actually the case. A comparison of units registered by the KVAH meter with the KWH meter is to be restricted to the period of full load conditions only, when the load power factor would be good, and meter would be working within the designed range.

(c) *Greater record of KVA demand on improvement of power factor.*—One feature of the compensated meter is that for the same load the meter would indicate greater KVA demand, on improvement of power factor. Thus for a meter with a working range of 0·7 to 0·95, the meter is adjusted 1·5 per cent fast at 0·85 power factor; and is 1·5 per cent slow at 0·95 and 0·7 power factors. The meter is say initially recording at 0·7 lag power factor. The record is 1·5 per cent less than true units. Now, if the power factor improves to 0·85 the meter begins to record 1·5 per cent more than the true units; and there is 3 per cent more registration than at 0·7 power factor. This is somewhat discomfiting, but is an inherent feature of the meter. If the load power factor improves further there is of course less registration and at power factor of 0·95, or thereabouts, the meter begins to register actually 1·5 per cent less than true units.

(d) *KVA demand being less than KW demand.*—It is sometimes found that the KVA demand indication in the compensated meter is less than the KW demand indicated. Thus, in the case of the meter, having a range of power factor 0·7 to 0·95, the KVAH meter would register the same as the KWH meter at a power factor of about 0·97, and for any better power factor, the KWH meter would register more than the KVAH meter. At a load power factor of 0·975, the KWH meter would register one per cent more; and at power factor of 0·98, the KWH meter would register 2·5 per cent more than the KVAH meter. This feature of the meter is also embarassing. This behaviour is noticed, however, only when the meter works at a load power factor, that is better than the range for which the meter is designed. The remedy in such cases is to ignore the demand reading, indicated by KVAH meter, and consider the KW demand as equal to the KVA demand.

Range of utility.

For the reasons stated above, the compensated meter has to be used with care, and they are normally used only in small installations, where the range of power factor variation under load conditions is definitely within the range of power factor of the meter. It is the Departmental practice to use the compensated meter only at installations with less than 200 KVA demand. A number of compensated KVAH meters were in service at one time in the Department, but most of these had to be replaced one by one, as the consumers

improved their load power factor, and the meter registrations became undependable, as the power factor range of the meter could no longer cover the actual load power factor. In some cases, the KVA demand. registered by KVAH meter was found to be actually less than the KW demand, indicated by the KWH meter.

KVAH meter without limitation of range.

Correct registration of KVA demand at a service is considered a matter of great importance, as an assessment on the basis of KVA, takes into consideration the power factor at the service and is more in conformity with the costs and capacities of equipments, lines and installations. Close and accurate metering of KVA demand has held sustained interest of service engineers for decades. Many different types of KVA metering have been evolved on a variety of principles.

Different types of KVAH meters.

Current meters have been developed, using shaded pole current electro-magnet and continuously driven disc. A permanent magnet is used for breaking. Three such elements and a common moving mechanism are used for a 3-phase meter. The registration is proportionate to current at a particular designed value and for other values the record is only approximate. Voltage is assumed constant, and the scale is marked in KVAH units and KVA. The assumption of constant voltage and insufficient accuracy at loads other than full load are deficiencies that are not quite capable of being accepted.

In another type, a phase shifter, responding to load power factor is inbuilt into the meter, and takes the place of the voltage electro-magnet in an ordinary energy meter. The 3-phase potential winding is connected to the supply through slip-rings. While in service, the phase shifter, being free to rotate, takes up the position, that would keep the rotating flux aligned with the current flux, when the latter is at maximum value. At this position, the potential flux, across the air-gap, is in time quadrature with the current flux; and the meter would therefore have the maximum torque. The meter, however, is essentially a single-phase meter and to measure three phase KVAH units, three meters would have to be installed, unless it be that the circuit is assumed to be balanced and the 3-phase KVAH units and demand are obtained by multiplying the readings of one meter connected on one phase by three. As the meter is a single-phase meter, it is not acceptable for three-phase measurement in the general case.

In yet, another type, alrernating voltages and currents are rectified and applied to the voltage and current coils of a D.C. meter. But such a meter is found to require filters in the voltage circuit to smooth the rectified voltage wave and remove pulsations in torque on the armature; and their introduction results in an error in the registration of the meter. Also in any rectified instrument a form factor has to be assumed for the shape of the voltage and current waves and any departure from the assumed values would result in appreciable error in the registration of the meter.

There are four types of KVAH meters, that are free from the defects noted for the above types and are also not limited to any particular range of power factor for their working. They are explained in some detail below :—

Westing House make KVAH meter.

The Westinghouse KVAH. meter gives a fundamentally correct registration of KVAH. units and KVA. demand indication, the exact registration being obtained by the use of an aluminium sphere, driven by friction discs, mechanically geared to the energy and reactive meters. The principle of the mechanism is illustrated below :—

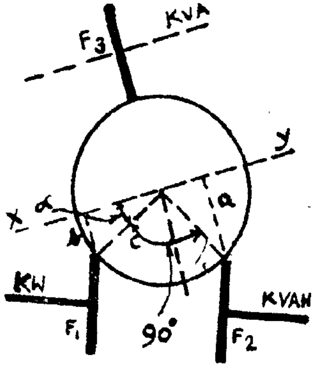


Fig. 1

Details of working of the meter.— In the Figure, the sphere is pivoted through its centre in a cradle frame about an axis at right angles to the plane of the paper. The sphere is driven by friction wheels F_1, F_2 of equal radii. The point of contact of the two wheels are 90 degrees apart on the surface of the sphere. The cradle is free to rotate about the same axis as the sphere and a third friction wheel F_3 of same radii as F_1, F_2 is attached to it. This friction wheel is driven by the sphere and the cradle frame adjusts itself to a position, that would keep the wheel in contact with the apex of the sphere, where the full peripheral velocity of the sphere gets communicated to it.

When load conditions are constant, there is no slipping of the friction wheels on the sphere and the peripheral speeds of the points of contact will be the same as those of the friction wheels at the points. If 'xy' is the axis of rotation of the sphere, 'c' is the radius of the sphere and the radii of contact of friction wheels F_1, F_2 are 'b' and 'a' respectively, the speeds of the two wheels are proportioned to 'b' and 'a' ; and the speed of the third wheel, F_3, is proportioned to, 'c'. It is seen in the Figure that $c = \sqrt{a^2 + b^2}$ and, therefore, the revolutions made by friction wheel, F_3, would represent KVAH. units, in the same scale, as KWH. and RKVAH. units are represented by the friction wheels F_1, and F_2. The motion of wheel, F_3, is communicated by an ingenious system of gearing to a fixed wheel, that actuates the KVAH. register and KVA. demand indicator. The KVAH. units registered and the KVA. demand indicated by the summation mechanism, the meters are therefore fundamentally correct : and there is no error introduced except by the error in the registration of the energy and reactive meters themselves.

The characteristics of the meter.—The meter effects a true vector addition of the actual and reactive power in the circuit, but to obtain this vectorial addition a system of friction wheels and an aluminium sphere have been introduced, which essentially is a cumbersome arrangement. Whenever changes in power factor occur the sphere changes its axis of rotation, and the friction wheels come into contact with new points on the sphere. If the changes are not gradual, the wheels would slip on the sphere. The movement of the KV AH. register would lag behind the movements of the energy and reactive meter registers under such circumstances; and the sphere would also get worn out in due course. The points of contact of friction wheels F_1, F_2 on the sphere for correct functioning of the arrangement have to be 90 degrees apart. If the sphere gets even slightly worn out, this would no longer be the case and the KVAH. record would be affected. The sphere has therefore to be periodically checked up to see if it is maintaining the spherical shape and also to ensure that there is but inappreciable surface-wear.

L & G make trivector meter.

In an L&G make trivector meter, proportions of rotations of the energy and reactive meters are added together so as to give for a particular power factor of load a summation speed that is equal to the maximum speed of the energy meter at unity power factor. There are three such separate aggregations and together with the two drives direct from the energy and reactive meters there are five systems of movement, and the arrangement, that is provided, is such that the system with maximum speed, actuates the KVAH. register and demand indicator.

Working of the meter.—If VA. is taken as unity, the energy meter records Cosθ and reactive meter Sin θ units. If fractions a, b of the two records are added up, the summated record would be—

$$= a \cos \theta + b \sin \theta$$

If a, b are equal to Cos d, sin. d. respectively the record would be

$$= \cos d \cos \theta + \sin, d. \sin, \theta$$
$$= \cos (\theta - d)$$

The value of the record is unity if $\theta = d$ The values of a, b are to be so chosen that $a^2 + b^2 = 1$: and $\tan d = b/a$.

In the L & G trivector meter, the values of a, b are so chosen that the summation, is maximum and equal to the KWH. record at unity power factor: and RKVAH. record at zero power factor; for values of load power factor angle of 22½ degrees for one summation, 45 degrees for the second summation and 67½ degrees for the third summation. The summation is obtained by epicyclic gearing attached to the energy and reactive metering gear.

The KVAH. spindle gets its movement from the energy meter drive, reactive meter drive, or any of the three summation drives with compensation angles of 22½, 45 and 67½ degrees. The gearing is through ratchet coupling and ensures that the KVAH. spindle always gets driven by the system having highest speed.

Characteristics of the meter.—The meter, therefore, behaves as a combination of three compensated KV AH. meters with mid power factor angles of 22½, 45 and 67½ degrees

incorporated with the energy and reactive meters and the meter having the highest speed, communicating its movement to the KVAH. register. As the angles of compensation are 22½ degrees apart, there is a maximum error in the indication due to change in power factor angles equal to Cos 11-1/4° or just 2 per cent.

Desirable features.—The device adopted to get the three compensation angles, at a short spacing of 22½ degrees is indeed ingenious and the meter gives a very reliable record of the KVAH. units and KVA. demand. The response to quick changes in the power factor of the load, in the indication of the meter is equally quick as no friction gear is involved.

The Transva M. V. meter.

The Transva meter, developed by Messrs. Metropolitan Vickers, Limited, operates on the principle that in any H. T. supply, the three voltages will be substantially balanced and as such the product of any one line voltage, and the arithmetical summation of the three line currents would closely represent the KVA. demand at the service.

Details of working of the meter.—The meter houses within its case a transductor, an auxiliary potential transformer, three auxiliary current transformers and a three-phase rectifier. The diagram of connection is given in Fig. 2. The twol-ine currents of the three-phase supply feed three auxiliary current transformers. The C.T. secondaries are connected to a three-phase rectifier and its D.C. output side feeds the control winding of the transductor. The transductor, has-two ring cores, each having an independent A.C.magnetising winding but the control winding is common. The current coils of the meter are connected in series with the A.C. windings of the transductor to the supply voltage through the auxiliary voltage transformer.

The metering portion comprises a single-phase induction type KWH. element, consisting of potential and series magnets, brake magnets, and adjustment facilities for full load and low load.

Under no load conditions, there is no current, in the control winding of the transductor. The A.C. windings therefore act as high impedances and practically no current passes through the current coils of the meter. Under conditions of load, the rectifier sums up the three line currents arithmetically, and the summated current magnetises and saturates the cores of the transductor during a period of the flux cycle, that is proportionate to the value of the control current. During the time, the flux is saturated, the A.C. windings of the transductor can offer but low impedance to the passage of current and in consequence an alternating current of some magnitude flows in the current coils of the meter. The value of this current is dependent on the value of the direct current in the control winding and is closely proportional to it. The alternating current is also in phase with the voltage applied to the potential winding. The driving torque is therefore proportional to the product of the voltage and the summated current.

Accuracy of the meter.—The meter is said to be accurate within plus or minus 2 per cent over a current

REFERENCE.

A—Auxiliary current transformers.

B—3 phase rectifier.

C—Metrosilunit.

D—Transductor.

E—Auxiliary voltage transformer.

F—Meter current coil.

G—Meter voltage coil.

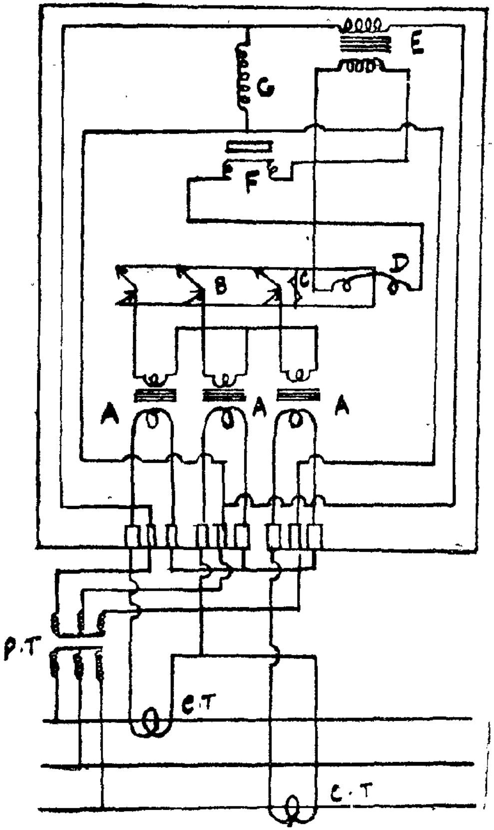


FIG. 2

range 5 per cent to 125 per cent. Efforts are said to be made for further improvement of accuracy. The variations in the indication of the meter due to changes in temperature and supply voltage do not exceed the limits permitted for an A.C. induction KWH. meter.

Desirable features of the meter.—The assumption of symmetry in the supply voltage is an acceptable proposition in a H.T. service connection; and its product with the arithmetical sum of the line currents is a close representation of volt-amp demand at the service. The meter registration is very satisfactory for unbalances in load. The principle of operation is simple and there are no cumbersome parts requiring special care. The meter is an independent unit and is not an addendum

to the energy and reactive meters, like other types.

The Ferraris KVAH. Meter.

It is possible to have a three-phase auto transformer, with a number of taps on the three phases, such that voltages equal to the line voltages and differing from it by angles 10 degrees to 90 degrees in steps of 10 degrees can be taken out from the terminal board, to which the tapping points are connected. If two sets of moving contacts are provided with a phase separation of 60 degrees and a 3-phase KWH meter is excited off these contacts, an arrangement is obtained, which would facilitate voltages, differing from each other by 10 degrees only, to be applied to the potential coils of the meter. The registration in a KWH meter, so energised would closely represent true KVAH units and the error in registration need not exceed cos. 5° or just 0·4 per cent.

Details of meter operation.—In a Ferraris meter, selection of the correct taps is made by a motor controlled by a power factor relay. The relay is excited by the same voltage as the KWH. meter and the function of the relay is to cause the voltage contacts to rotate until the apparent power factor in the relay is unity. Under such conditions the potential supply to the meter is maintained nearly in the unity power factor condition and the meter runs at maximum speed.

Characteristics of the meter.—One favourable feature in the above arrangement is that an ordinary energy meter itself is made to record KVAH units and there would, therefore, be two KWH meters in service at the installation, one to record KWH and KW demand and the other to record KVAH units and KVA demand. The power factor relay and auto transformer, and motor operation of selection contacts, make the arrangement somewhat cumbersome and the response to changes in load power factor is affected by friction at the contacts.

Conclusion.

It is Departmental practice to use trivector meter only in all important H.T. services with demands above 200 KVA, The trivector meter registers the active and reactive power in the circuit and the KVAH units and KVA demand are recorded by the summation mechanism introduced in between the energy and reactive meters. The trivector meter has been found in general to function satisfactorily. The overall error of 2 per cent in the registration due to the summation mechanism is also satisfactory. The Westinghouse KVAH meter, however, deserves to be given a trial in a few services to assess its practical utility.

The auto-transformer combination is a useful arrangement in a laboratory for conversion of a KWH. R.S.S. to a KVAH. R.S.S., for any particular load power factor at which the KVAH. meter is being tested. As the compensated KVAH. meter is deficient and has to be used with a good amount of care, that cannot normally be exercised at the field, and the Transva meter is an all-range meter, not restricted to any particular power factor, the feasibility of using the 'Transva' type meter deserves favourable consideration, in small installations, where limited-power factor KVAH. meters are used for the present,

21 APR 1958

Repairs on the 6 M.W. Turbo-set at Basin Bridge

By M. THIRUNAVUKKARASU, B.E.,
Assistant Engineer (Mechanical).

Introduction.

THE AUTHOR

SEVERE vibration was observed on 29th May 1951, at the H.P. end of the 6 M.W. B.T.H. set at the Basin Bridge Power Station. The Steam Baffle at the H.P. end between the gland and the bearing was found to have become red hot. The turbo-set was immediately shut down. On examination, it was noticed that the thrust collars of the thrust-block had melted, resulting in the steam rotor moving towards the alternator side by $\frac{1}{16}$th inch, thereby causing damage to H.P. gland rings. Necessary repairs were carried out on the steam rotor bearings, thrust block, H.P. gland box and H.P. casing. The H.P. gland box was very badly damaged and had to be repaired at site, as a spare gland box was not available for immediate replacement. The Set was satisfactorily commissioned on the 28th August 1952 after completion of repairs and pre-commissioning tests. A new gland box was also ordered for and obtained from the makers.

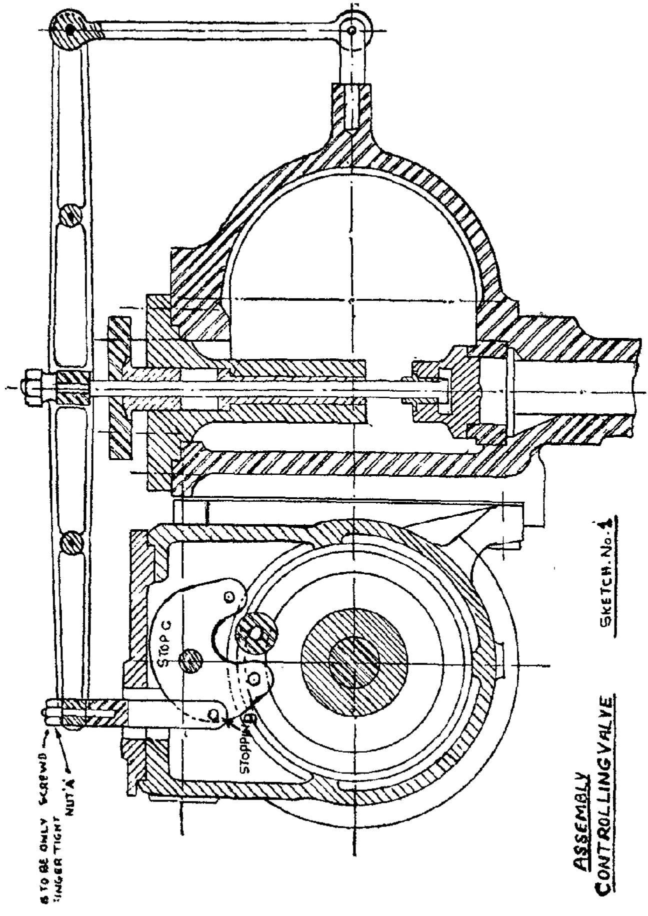
It was reported in first week of May 1955, that the electrical rotor insulation resistance was very low. It was then decided to replace the repaired gland box and packing rings with the new H.P. packing box, which had arrived at site. It was also programmed to overhaul the turbine in addition to the assembly of the new gland box. The rotor and connecting leads to the slip rings had also to be inspected on routine. On 9th May 1955, the machine was taken out of commission for carrying out all pending works.

Defects observed.

On opening out and examining the turbine, the following defects were noticed :—

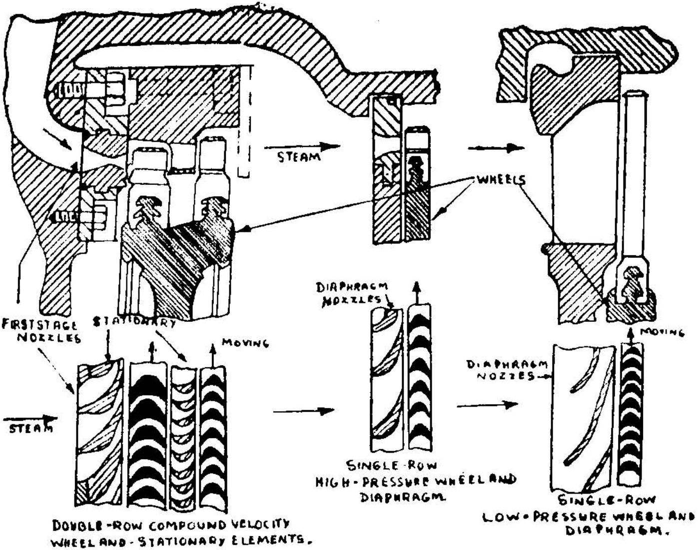
(1) A few blades in the H.P. nozzle plate and a few rotor blades were found dented.

(2) The shrouding in the first-stage wheel was badly eroded.



ASSEMBLY
CONTROLLING VALVE

SKETCH. No. 4



SKETCH. No 2 DIAGRAM ILLUSTRATING TYPES OF STAGES IN B.T.H. TURBINES.

(3) Control valve seatings and valves were badly pitted.

(4) The H.P. packings had worn out beyond the limit clearance, causing a heavy steam leak from the gland.

Sketch 2 illustrates types of stages in the B.T.H. turbine.

Rectification of defects.

The repair works carried out are detailed below :—

Rotor blades.—The dents in the rotor blades, H.P. nozzle plate and fixed blades were straightened. The blades were then polished.

H.P. Wheel shrouding.—The erosion on the H.P. wheel shrouding was considerable and for th esafety of the plant, it was decided to renew the shrouding. This operation required considerable skill and care, as it was necessary to ensure that each new shrouding segment corresponded with the old shrouding removed from the wheel. It was not sufficeint to have the segments of the same length; considerable care had also to be taken to see that each segment was of the same weight. Unfortunately no new shroudings were availabe on hand. It was therefore decided to make the shroudings out of stainless steel at the Power Station workshop itself. When the new shrouding was assembled and rivetted on to the blades, it was carefully machined to give the desired clearance between the nozzle plate and first stage wheel. As no suitable lathe was available for machining such a big rotor the shroudings were machined by fixing a special carbon tipped tool to the bottom half of the casting, using the same as a tool rest.

Control valves.—Considerable difficulty was experienced in removing the old seats form the control valvecasing. Special pullers were made and it was only possible to withdraw three out of the seven seats. The others were cut by hacksaw blades, taking sufficient care to prevent any injury to the body. New seats were fitted satisfactorily. New valves and spindles were fitted to the control valve levers in the following manner (vide Sketch 1).

With servo-motor blade hard over in shut position, the length of the ferrule is to be adjusted so that there is 1/8 inch clearance under cross head, when valve is hard on its seat and nut 'A' is slacked off to allow stop pin 'B' to bear on circumferrence of crank disc.

When servo-motor is turned to point of maximum lift on each rocker, it must be seen that it is possible to lift the link and end of the lever at least 1/8 inch more before stop pin 'B' touches stop 'C'.

Gland box.—The new gland box had been ordered to be delivered undrilled with the connecting flange a little over size for machining. The flange, thickness had therefore to be reduced so as to keep the serrated edge of the gland packing in the centre of the grooves in the packing box with the turbine rotor in the running position. Measurements were taken to determine the exact amount to be machined from the joint face of the gland box. The joint face was machined allowing a few thousands over-size to facilitate proper bedding of the joint between the H.P. casing and H.P. gland box by grinding the faces. It was not possible to attempt grinding in the vertical plane. The H.P.

casing wasdisconnected from theL.P. casing and the two H.P. halves were connected with the diaphragms in position, so that they registered properly and were then placed on the basement floor to carry out the work. After grinding the face to the required size, the high spots were removed by scraping. Holes were drilled on the joint face of the gland box and the gland box was then dowelled to the H.P. casing and fitted up.

Gland packings.—The old gland packing rings were not found suitable for the new gland box. A new set had to be used. These new packing rings were bedded and the radial clearances were adjusted to 0·10 inch. A total gap of ·048 inch was given at one joint of the four segments to allow for expansion of the rings after bedding the jointing faces of the 4 segments. It was then observed that the gland box had to be moved out to have the shaft gland rings in a central position, with the turbine in the running position. To make this possible the gland box was taken out and connected back with a 1/64 inch steam joint. When all component parts were re-assembled and checked, the clearances were found to be in order.

H.P. steam baffle.—The existing steam baffle was used by making new crushing pins for both top and bottom halves. The baffle with new pins was crushed in postion and the circumferential total clearance of .01 inch was maintained.

Thrust bearing.—This bearing was found in perfect condition and the same bearing was used after cleaning and bedding the same.

L.P. gland box.—The L. P. gland is sealed by carbon rings consisting of three segments in each ring, which are held together with a garter spring round the periphery. The segments were bedded so that they but together at the ends to make the steam tight joint. The clearance between the shaft and the carbon ring was adjusted to ·01 inch.

Conclusion.

During the course of repair work, all the auxiliaries were overhauled and new parts were fitted up wherever found necessrary. The Turbine was coupled to the alternator after checking the alignment with the shaft gauge. The exciter was also aligned and coupled. The set was run at full speed on 16th September 1955, for 20 minutes and the performance was found satisfactory. The emergency governor was tested on 17th September 1955 and operated on 1650 revolutions per minute. On 17th September 1955, the Set was tested on half load and found satisfactory. On 26th September 1955, the Set was released for operation and was immediately put on commercial load.

The fitting and machining of the new shrouding, the assembly of new the H.P. packing box, and labyrinth packing rings took some considerable time to complete.

The powerhouse fitters were found suited to do such skilled work. The time factor of work can be reduced by constant practice alone.

Mr. R. Mc. G. Morren, Assistant Generation Superintendent, Basin Bridge Power Station, carried out the complete work on the machine. The author is grateful to Mr. Morren for his valuable help and guidance in compiling this article.

Balancing of Rotary Convertors

By S, SIVASUBRAMANYAM,B.E.
Assistant Engineer (Electrical)-

SEVERE VIBRATIONS in the bearings as well as onbed of one Rotary Convertor at West George town Sub-station were observed early in September 1954. This Rotary Convertor is a 250 KW machine, B.T.H. make 1500 r.p.m. with main bearings, spaced 5 feet 6 inches centres, and the rotor weighing about one and a quarter tons. The vibrations were so severe as to be felt on the walls and the glass shutters of the Station. In this article, an endeavour is made to describe, how the vibrations were eliminated and the machine re-commissioned.

THE AUTHOR

Causes for vibration.

It was felt that the following causes, besides unbalance in the rotor, could contribute to the vibrations observed :—

(1) Uneven and highly worn out bearings.

(2) Loose foundation bolts and improper alignment of bearing pedestal.

(3) Uneven air gap and unsymmetrical field coils causing uneven magnetic pull on the rotor.

(4) Slight bend in the shaft causing uneven throw in the bearings.

The above causes were investigated in detail and checked up and rectified. The white metal bearings of the machine were found to have a top clearance of about 34 to 36 mils for a shaft diameter of 3 inches. These were considered high and the bearings were replaced with spare ones available and clearances adjusted to about 10 to 11 mils.

The foundation bolts were all checked and tightened up and the level of the shafting with rotor was checked by accurate spirit levels and found to be satisfactory.

The air gap width of the rotor and stator were also checked and found to be satisfactory. Tests on the main shunt fields were conducted to find out equality of D.C. resistance of the coils and A.C. drop tests were carried out to find out short circuited turns. The tests proved that the fields coils were satisfactory.

The top bearings on both A.C. and D.C. sides of the machine were removed and after suitably clamping the bottom bearings, dial gauges reading up to halfamil deflection were placed on the shafting and the

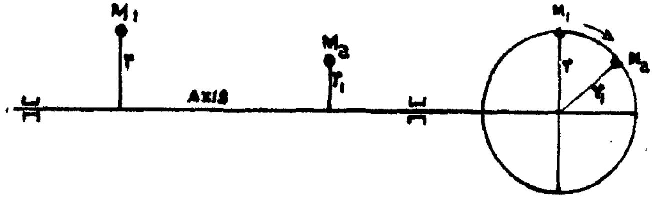


FIG. 1.

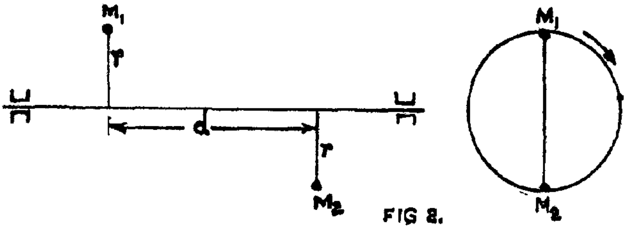


FIG 2.

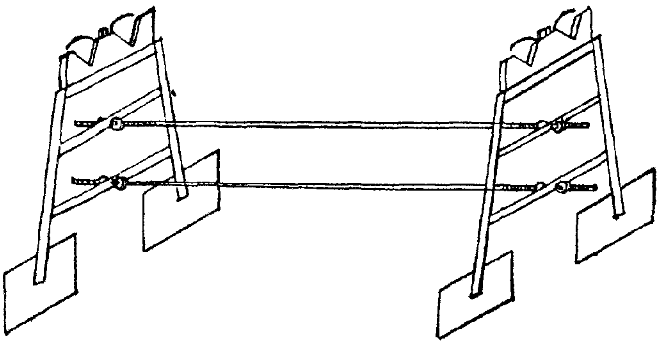


FIG. 3.

rotor slowly rotated to detect any bend or throw in the shafting. This test proved that the shafting was not bent as the dial gauge recorded no deflection. It was concluded that the vibrations felt were due to unbalance in the rotor and it was therefore decided to statically balance the rotor under the direction of Mr. R. Mc. G. Morren, Assistant Generation Superintendent at Basin Bridge Power House. From the previous history of the rotor, it was also gathered that the slip rings in this rotor had been damaged, which could have introduced unbalance in the rotor.

Types of unbalance.

The types of unbalance on the rotating parts of a machine can be classified into Static unbalance and Dynamic unbalance.

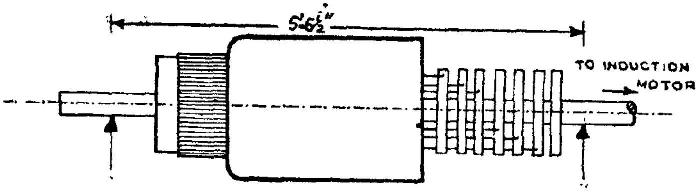
In the case of Static unbalance the centre of gravity of both moving masses M_1&M_2 as in Fig. 1 may be in the same axial plane and on the same side of the axis of rotation. The same centre of gravity of the whole body will be inthe same plane at a distance from the axis of rotation. This can be detected by a static test. If the rotor is moved slightly off the shaft it will roll on the bearings till the centre of gravity reaches the lowest position.

The Dynamic unbalance occurs when the machine is running. If the centre of gravity of both the parts as in Fig 2. are in the same axial planes but on opposite sides, and at such a distance that the centre of gravity of the whole body is in the axis of rotation, the body will be in equilibrium under static conditions. But during rotation, a disturbing couple is set up by the centrifugal forces acting on the rotor This couple will rotate with the body and produce vibrations on the foundations. In most general cases, the centre of gravity of the two parts may lie in different axial sections and during the rotation a system of two separate couples formed by centrifugal forces will act on the body. This system can however be reduced to a single couple acting in an axial section. These types of unblances are determined by various types of balancing machines, and the vibrations are recorded by vibrometer of the Seismograph type and weights are added at suitable places and the unbalance removed. The Static balancing equipment and the Reed type vibrometer used for the balancing of the Rotary Convertor rotor in this case are described below .

Static balancing equipment at Basin Bridge Power House.

The sketch of the equipment at Power House which was used for static balancing of the rotor is given in Fig. 3. This consists essentially of two brackets, made of 4 inches x 2 inches mild steel channels, shaped and welded with cross stiffeners, and two longitudinal 3/4 inch diameter long ties, and capable of varying the distance between the brackets to suit length of shaftings. Mounted on the breakets are two V blocks with a central half clamp to hold two bits of 3 inch diameter steel shaftings. Mounted on the two shafting ends are two ball bearings with their outer racers covered by tempered steel wedge shaped casings as shown in Fig. 4.

The Rotary Convertor rotor in question was first put on lathe and the commutator and the slip rings



ROTOR OF ROTARY CONVERTER

FIG. 5

DC SIDE END VIEW

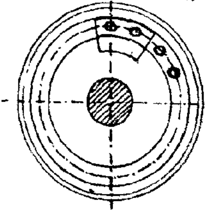


FIG 6

A.C. SIDE END VIEW

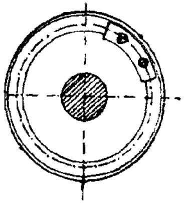


FIG. 7

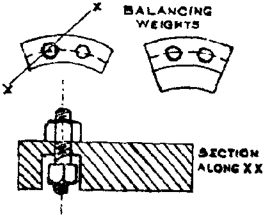


FIG. 10

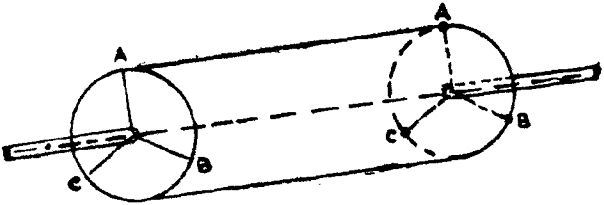


FIG. 9.

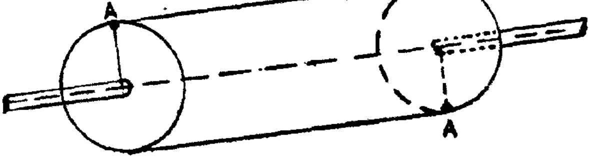


FIG. 11

were turned to remove the outages on the slip rings and commutator. After adjusting the level of the static balancing equipment and casing up the ball bearings, the rotor was placed in position and statically balanced. Fig. 5 shows the view of the rotor, and provisions, available on the A.C. and D.C. ends of the rotor, for placing balancing weights, are shown in Figs. 6 and 7. During the process of balancing, it was seen that due to inherent friction on the ball-bearings and slight inequality of levels of the stands, the rotor shaft had a tendency to crawl to one end of the stands and the hardened knife-edged outer racers first used on the ball-bearings had a tendency to score the polished surface of the shafting. To avoid this the knife edges on the outer racers were replaced with slightly flat-topped racers as shown in Fig. 4. The balancing weights added to get static balance in this equipment totalled about 64 ounces including the original weights of about 18 ounces on the rotor. These weights were distributed as 21 ounces on the D.C. end and 43 ounces on the A.C. side. Since the originally-provided weights on the A.C. side were found to foul the bearing pedestal end-covers on the machine due to restriction of clear space available, these were replaced with lead weights enclosed in a mild steel welded casing of a narrower width. The rotor so balanced was replaced on the machine with a set of newly-metalled bearings. The machine, when finally run, was found to have improved in running conditions and the vibrations recorded were found reduced by 50 per cent in amplitude, even though this was still considerable. The work on the machine, at PowerHouse, was carried out under the guidance of Mr. Morren, Assistant Generation Superintendent. The machine was later adjusted for running balance with the use of the Reed vibrometer at site.

Running balancing with Reed vibrometer.

The vibrometer used was Kelvin Bottomley and Bard (K. B. & B.) reed type vibrometer, a sketch of which is given in Fig. 8. This vibrometer has a vertical scale with adjustable screw, which varies the length of the reed used, and has a horizontal scale to measure the amplitude of the vibrating reed. The vibrating reed is fixed firmly at the bottom by a thumb screw A (videFig.8) and the movable vertical slide screw B carries a spring grip clamp C, which determines the length of free reed. The reeds carry on top, varying weights.

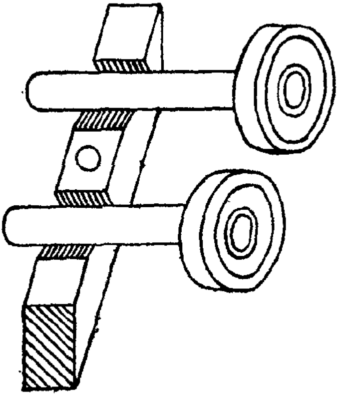


FIG. 4.

The reeds with smalier weights can be used for the higher frequencies and the reeds with heavier weights for lower frequencies of vibrations. The vibrometer has also two sets of bottom plates so that it can rotate about its own axis and also at another axis 90° from its own. The bottom plates are graduated to read the angle of inclination and the angle of rotation of the vibrometer, thus facilitating readings being taken of vibrations in 2 planes at one setting of the instrument.

Two sets of similar clamps were fixed on the A.C. and D.C. end pedestals of the rotary convertor for handling the instrument and these were not disturbed throughout the balancing operations. Both the vertical and transverse vibrations were measured and the vertical vibrations were found to be greater in this case.

The location of the static balancing weight in the rotor end is determined by the following method (vide Fig. 9). Two trial weights of about 6 to 8 oz. are fixed one each at D.C. and A.C. ends of the rotor in the same plane and on the same side of the shaft and the machine run to its rated speed. The amplitudes of vibrations are recorded. The length of the reed is adjusted by slide screw B till maximum amplitude of vibration is obtained, as read on the horizontal scale. The amplitude of vibration becomes maximum, when the natural frequency of the free length of reed coincides, with the rotor frequency. The readings are repeated with the balancing weights fixed at position B 120 degrees away from A; and at 'C' 240 degrees away. From the above three readings of amplitudes of vibrations the position wheree the minimum, amplitude is obtained is determined and the balancing weights are placed here.

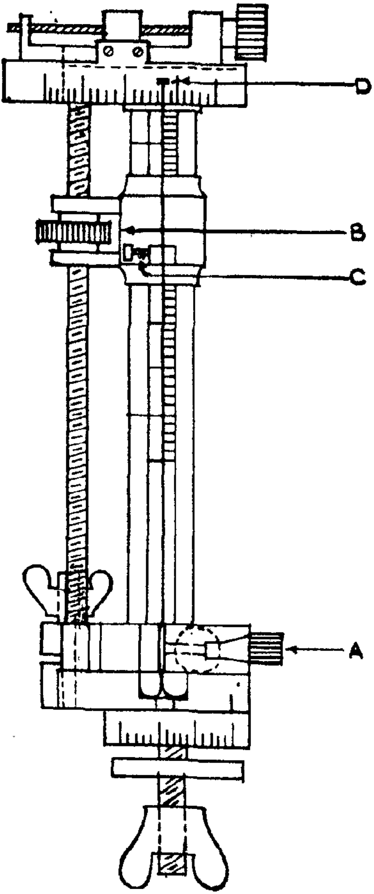


FIG. 8.

Using the reed vibrometer described above amplitudes of vibrations in three positions were noted, as explained above; and the location of minimum amplitude was determined. The balancing weights were fixed $22\frac{1}{2}$ degrees on either side of this position and the tests repeated. The weights were finally fixed at positions which gave the minimum amplitude of vibration. The balancing weights were then increased by 8 oz., i.e., 4 oz. on each end and the readings of vibrations recorded for each run. The test runs indicated that the vibrations were getting reduced as the weights were increased and finally the amplitude of vibration became almost negligible with the total balancing weights at 91 oz., i.e., 43 oz. on the A.C. side and 48 oz. on the D.C. side.

There was practical difficulty in adding weights made up of $\frac{1}{8}$ inch M.S. plates cut to shape and drilled to take the fixing bolts, as the length of the fixing bolt available was limited. Specially-shaped balancing weights of about 16 to 20 oz. were made and fixed as shown in the Fig. 10.

Another difficulty was that the number of times the rotory converter could be started and run to speed at a time was limited by the heating caused in the starting motor windings. The tests had to be prolonged over a number of days, due to this.

Dynamic Balancing.

After eliminating the static out of balance as described above dynamic out of balance was eliminated in the following manner. Trial balancing weights of about 4oz. were placed one at each end of the shaft, but placed diametrically opposite to each other, as shown in Fig. 11.

The machine was then run and readings of vibrations taken. This procedure was repeated with the trial balancing weights shifted around 120° and then another 120°. From the peak readings of these three runs the minimum reading position is determined and at this position the weights are increased further to see the improvement in the running conditions obtained. Difficulties were encountered, during these tests as the rotary converter had static balancing weights already fixed at either ends, and when additional dynamic balancing was required at the same place, they had to be replaced by heavier weights of suitable shapes and dimensions.

After balancing statically and dynamically, the machine was put on trial run, connected up and commissioned. The machine is now running smoothly and vibrations are found to have been completely eliminated. Two more rotary converters of 250 K.W. capacity were balanced on similiar lines successfully and commissioned back into service.

Conclusion.

Since these rotary converters should have been balanced at works before erection at site, the reasons for such vibrations developing now merit consideration.

One of the chief causes, which disturb the balance of the rotor of high-speed machines is the unequal or uneven wear on the commutators or slip rings as the stoning

usually adopted to remove patches on the collecting surfaces, tends to deform the surface to an oval circular shape, thus bringing about eccentric weights into play.

Another cause for unbalance would be the changes in weights introduced on the periphery of the rotor due to replacement of coils and also due to lugs and connections re-soldered from time to time.

Yet another cause may be due to the machines, being accidentally run condsiderably above the rated speed, when the end windings may shift and become a little eccentric.

Every major change in the slip rings or commutator may bring about a change in the running balance of the rotor due to blow holes in the castings or materials.

It will be worthwhile to keep in mind the above causes while dealing with running machinery and adopt suitable precautions, to enable the machine being kept balanced.

APPENDIX

Principle of Vibrometer.

The reed of the vibrometer which is fixed at one point vibrates with an amplitude E_A or E when it is subjected to a periodical disturbing force. In a running machine, any lack of balance in the arrangement due to centre of mass lying away from the axis of rotation introduces a reaction force on the shaft in a radial direction. This has components in directions at right angles, horizontally and vertically, say, which are periodic disturbing forces in three directions with frequency equal to the speed of rotation of the shaft. Thus the vibrometer fixed to the pedestal of the shaft is subjected to the above, disturbing forces.

The motion of the reed, subject to a periodic disturbance, follows the harmonic law. Its equation takes the form. $P \sin p_1 t - Sx = \frac{W}{g} \frac{d^2X}{dt^2}$ where P is the maximum value of force applied with a frequency $P_1/2_{\Pi}$ cycles/sec and W/g, the mass supported on a spring of stiffness S. The second and important part of the motion is the motion of the body under the action of the disturbing force. This is called forced vibration, and its amplitude depends on that of the disturbing force and also *in a pronounced manner on the* relationship between the natural frequency of the body and the frequency of the applied force.

The equation can be written as :—

$$\frac{d^2x}{dt^2} + P^2X = \frac{P}{S} p^2 \sin p_1 t.$$

on writing $\frac{Sg}{w} = P^2$ and $\frac{g}{w} = \frac{P^2}{S}$

The solution of this equation is in two parts corresponding to the components of motion due to free vibration and forced vibration.

The first solution is $\frac{d^2x}{dt^2} + P^2X = 0$.i.e., $X = A \cos Pt + B \sin Pt$.

Where A and B are constants of integration. The second solution which is a particular value of X, called the particular integral, representing the forced vibration, is found by substituting $X = M \sin P_1 t$; and $\frac{d^2x}{dt^2} = -P^2 M \sin P_1 t$. *in the equation.*

The equation now becomes:

$$-P_1^2 M \sin P_1 t + P_1^2 M \sin P_1 t = \left(\frac{P}{S}\right) P^2 \sin P_1 t$$ which requires

$$M = \frac{P}{S}\,\frac{P^2}{P^2-P_1^2}$$ Thus $X = P_1^2$

$$\frac{P}{S}\sin P_1 t.\ X\ \frac{P^2}{P^2-P_1^2}$$

Thus complete solution of equation repesentng the motion of body is given below :—

$$X = A \cos Pt + B \sin Pt. + \frac{P^2}{P^2-P_1^2}\sin P_1 t.$$

In practice, the component $= A \cos pt + B \sin Pt$ due to free vibration would ultimately disappear owing to friction losses and evaluation of A and B is therefore not necessary. Considering forced vibration only, its amplitude is equal to the statics deflection of the body under a force steadily applied (i.e. + P/S multiplied by a factor which depends on the ratio of the frequency of the applied force and the natural frequency of the applied force and the natural frequency of the body. This ratio, called Dynamic multiplier, can be determined for various values of P_1/P.

Thus the displacement of the vibrating reed of the vibrometer, relative to the body of the instrument fixed to support on the machine is (considering forced vibrations only)

$$X - y = \frac{P^2}{P^2-P_1^2} = y \sin P_1 t - y_1$$

Sin P't and the dynamic multiplier for the relative motion in terms of support is $Z\frac{(P_1/P)^2}{1-(P_1/P)^2}$ and value of Z for a range of P_1/P is as below :—

P_1/P	Z	P_1P	Z
0	0	1·1	−5·8
0·2	0·04	1·2	−3·27
0·4	0·19	1·4	−2·04
0·6	0·56	1·6	−1·64
0·8	1·78	1·8	−1·45
0·9	4·20	2·0	−1·34
1·0	infinity	3·0	−1·13

Thus for low applied frequencies, the relative motion is small, and in phase with the support, increasing with frequency to resonance. It then becomes anti-phased and decreases in magnitude until at relatively high frequencies, when the body is almost at rest, the relative movement is equal to the actual movement of the support.

Thus when the applied frequency equals the natural frequency of the reed (i.e.) p_1/p approaches unity, the amplitude of vibrations becomes large and this condition is called resonance.

21 APR 1957

Progress During the Quarter Ending 30th June 1956

Salient Features.

The inflows into the Pykara dam, Mukurti lake, Mettur and Papanasam reservoirs were poor during April and May, but they improved in June. Cuts in power supply were imposed on all non-essential loads during the period 1st April to 28th June 1956 to extents varying from 25 per cent to 66-2/3 per cent.

The Department earned a revenue of Rs. 191·02 lakhs as compared to Rs. 187·92 lakhs during the previous quarter. The working expenses during the quarter amounted to Rs. 113·95 lakhs and the capital expenditure incurred was Rs. 91·20 lakhs as against Rs. 96·95 lakhs and Rs. 478·58 lakhs respectively during the previous quarter.

Supply was extended to 3,081 agricultural, 301 industrial and 7,533 domestic services. Also, 227 villages were electrified: and 391·0 miles of H.T. lines and 520·5 miles of L.T. lines were erected and energised during the quarter.

The Department participated in the Seventh Municipal Exhibition held at Tirunelveli from 10th June to 1st July 1956.

The Kundah-Hydro Electric Scheme was inaugurated by Sri C. D. Deshmukh, Ex-Union Finance Minister, on 29th June 1956.

Construction Branch.

Madras Plant Extensions.

Under the II Stage extensions, erection of boiler No. 5 and chimney was in progress. The re-routing of steam interconnection pipe and drain pipe and lagging works thereon were completed. The entire steel work was erected, plinth for F.D. fan was completed and work on the plinth for I.D. fan was progressing.

Under the III stage extensions, 12 Nos. anchor bars for the foundation bolts of boiler columns were laid *in the* R.C.C. foundation. South side wall of north goit was completely dismantled. All the 681 piles were driven, thus completing the piling work in power house area. Work of cable trench was nearing completion.

Pykara Plant Extensions III Stage.

Erection of spillway gates was completed . The gates were tested for satisfactory operation.

Periyar Hydro-Electric Scheme.

The cost of patta lands required for the project was deposited. Roads to valve house and in lower camp were progressing. The permanent bridge in power house road was nearing completion. All the permanent buildings in lower and

upper camps were completed. Telephone system was completed. Staff quarters at Theni were also completed.

In the irrigation tunnel, major portion of the widening was completed and about 740 feet of floor were concreted. Excavation in forebay dam was nearing completion. The power house tunnel was completed and lining with concrete was commenced. Excavation for pipe tunnel was completed and trimming was progressing. The penstock grading was completed except in the last reach near power house. Excavation for penstock bridges 2 and 3 and diversion channel was over, and construction was started. Excavation for anchor No. 4 was in progress, and that of power house and tail race was almost completed. Tail race works were completed.

KUNDAH HYDRO-ELECTRIC SCHEME.

The Scheme was inaugurated by Sri C. D. Deshmukh, Ex-Union Finance Minister on 29th June 1956. Construction of camp quarters was taken up and was in progress. For P.H. No. 2, work on road from Manjoon to power house was progressing. Route for tunnel No. 2 was fixed up. For penstock No. 2, jungle clearance was nearly completed. The power house area was cleared of all bushes and trees and the site was demarcated. In the forebay dam, excavation for foundation and drilling of bore holes were progressing.

Excavation and drilling for P.H No. 1 and clearing of plantations along the slope of penstock No. 1 was progressing. Roads from Kundah Bridge to Edakadu, Yidakadu to Emerald camp and Karamadai to power house were in various stages of progress.

In the emerald dam, drilling of bore holes, building of retaining walls, laying of tract lines to quarries, etc., were continued. In avalanche dam similar works were in various stages of progress.

TRANSMISSION LINES.

1. *Salem–Namakkal* 110 *K.V. line.*—Materials and equipments received from suppliers were transported to site. Foundations for the 22 K.V. structures, 22 K.V. O.C.Bs. and 110 K.V. switches were concreted. Erection of 22 K.V. structure was completed. Erection of 110 K.V. switch structures for transformers was completed. Construction of quarters for Rasipuram and Namakkal sub-stations was continued.

2. *Singarappet-Villupuram* 110 *K.V. line.*—The line works were completed and the line tested with H.T.D.C. The line was energised up to Tiruvannamalai end, to give additional relief to Villupuram end and to improve voltage conditions. Diversion of telephone line was nearly completed. In the Villupuram and Singarappet Sub-stations, construction of quarters was progressing.

3. *Singarappet-Vellore* 66 *K.V. line.*—Stringing of conductor, and earth-wire, and earthing of tower fittings were nearly complete. Painting was completed. Construction of the control room at Vellore Sub-station was continued.

4. *South Kanara Scheme.*—All works connected with the 110 K.V. lines were completed. The Udipi-Coondapur 33 K. V. line was completed.

5. *Villupuram-Pondicherry* 66 *K.V. line.*—Stubs for towers were received and arrangements were being made to start excavation and stub-setting from Pondy end.

6. 110 *K.V. D.C. line—Travancore-Cochin State border to Udumalpet.*—Survey work was completed. Profiles and schedules were prepared. Materials were ordered.

7. *Periyar Transmission Lines*—(*a*) *Periyar-Theni* 110 *K.V. D.C. line.*—Profiles and schedules were prepared. Check survey was completed for a length of 33 miles. Excavation for tower foundations, stub-setting and concreting were commenced.

(*b*) *Theni-Madurai* 110 *K.V. D.C. line.*—Profiles and schedules were prepared. Tree clearance was completed except for trees belonging to other departments and local bodies.

(*c*) *Theni-Sembatti* 110 *K.V. D.C. line.*—Excavation for tower foundations, stub-setting and concreting were continued. Construction of quarters and control room at Theni Sub-station was progressing.

(*d*) *Sembatti-Tiruchi* 110 *K.V. D.C. line.*—Profiles and tree valuation schedules were completed.

(*e*) *Sembatti-Karur* 66 *K.V.D.C. line.*—Tree valuation schedules were prepared. Check survey and excavation were progressing.

Works on the sub-stations of the above lines were in various stages of progress.

OPERATING SYSTEMS

HYDRO SYSTEMS.

A. GENERATION.

The inflows into the Pykara dam, Mukurthi lake, Mettur and Papanasam reservoirs were poor but improved towards the end of the quarter, in June.

All the systems were run in parallel during the quarter. Cuts in power supply were imposed on all non-essential loads with effect from 1st April to 29th June 1956 as under :—

Period of cut.	PER CENT.
1st to 29th April 1956	25
30th April to 20th May 1956 ..	50
21st to 31st May 1956	66-2/3
1st to 6th June 1956	50
7th to 28th June 1956	25

The entire cut was lifted on **29th** June 1956, the day of inaugbration of Kundah Scheme.

The station peak-load, system peak load, and units generated were as follows :—

Name of System/ Station.	Station peak load in M.W.	Units generated in millions.	System peak load in M.W.
Pykara	68·00	79·102	55·05
Moyar	34·00	31·388	..
Mettur	23·30	18·345	59·1
Papanasam ..	26·00	17·573	24·9
Madurai Thermal Station,	11·50	20·227	..
Udipi	0·44	0·259	..
			139·05

The following services were connected during the quarter :—

Name of System/ Station.	Agricultural.	Industrial.	Domestic.
Pykara	885	109	2,205
Mettur	992	35	1,056
Papanasam	386	15	2,587

B. DISTRIBUTION.

Pykara Electricity System—The 110 K.V. switch gear modification works at Coimbatore Receiving Station were progressing. The Madurai-Coimbatore 110 K.V. line was charged up to Madurai on 11th May 1956. Works connected with Madukarai-Palghat 66 K.V. line, Ingur-Olapalayam 33 K.V. line and Kangayam-Vellakoil 33 K.V. line were in progress.

Mettur Electricity System.—The Erode-Tiruchirappalli III Circuit was changed over to 110 K.V. operation from 15th April 1956. The 12 MVA. 110/66 K.V., E.E. auto-transformer was commissioned at Tiruchirappalli Sub-station. The new Singarappet-Villupuram 110 K.V. line was charged at 66 K.V. on 20th May 1956 up to Tiruvannamalai and connected to the existing Tiruvannamalai-Villupuram 66 K.V. line on 27th May 1956. The diverted Tiruchi-Tanjore double circuit tower line was charged on 20th May 1956.

During the quarter, tower and line materials were manufactured in the Mettur Workshops, to the total value of Rs. 10·42 lakhs.

Papanasam Electricity System.—The Sattankulam Sub-station was energised at 33 K.V. on 25th April 1956. The new 11 K.V. line to Shermadevi from Melakallur Sub-station was charged.

Thermal Systems.

MADRAS ELECTRICITY SYSTEM.

The station peak-load, system peak-load and units generated were as under :—

Name of Station.	Station peak load in M.W.	Units generated in millions.	System peak load in M,W.
'A' Station	16·5	25·568	39·6
'B' Station	28·0	49·668	..

The services connected were as under :—

Agricultural	..	818
Industrial ..	..	142
Domestic ..	..	1,685

Relief was given to hydro areas during the quarter.

The major works attended to during the quarter were as under :—

1. Extension 11 K.V. mains from water works to Kilpauk sub-station.

2. Laying of 11 K.V. feeder between Mount Road P.O. to Big Street P.O.

3. Extension of A.C. supply to St. Thomas Mount.

4. Change-over of 5 K.V. supply to 11 K.V. at Saidapet.

5. 11 K.V. supply to Kanchee town distribution, off 66 K.V.

6. Erection of outdoor sub-stations at Sembium, Adyar, etc.

7. Erection of switch gear at East G.T. Sub-station, Royapuram Sub-staion, etc.

Besides the above 166 major construction works were in various stages of progress.

During the quarter 1093 D.C. services with a connected load of 1087 K.W. were changed over to A.C. on a voluntary basis.

Rural Electrification.

The number of villages electrified during the quarter under review in the several systems was as follows :—

Pyakra System	..	33
Mettur System	..	63
Papanasam System		58
Madras System	..	73
Total	..	227

The length of lines energised under the various schemes for rural electrification were as follows :—

System	H.T. MILES.	L.T. MILES.
Pykara ..	56·65	131·44
Mettur ..	156·28	182·14
Papanasam ..	63·08	122·93
Madras ..	114·96	84·02
	390·97	520·53

Accounts Branch.

The Department earned a revenue of Rs. 101·02 lakhs, as compared to Rs. 187·92 lakhs during the previous quarter. The working expenses amounted to Rs. 113·95 lakhs as against Rs. 96·95 lakhs during the previous quarter. The apparent increase is due to transaction under suspense.

The capital expenditure during the quarter amounted to Rs. 91·20 lakhs against Rs. 478·58 lakhs during the previous quarter.

Technical Branches.

A. ELECTRICAL.

For the Periyar Hydro-Electric Scheme, contracts were placed for the following :—

(i) Supply and erection of generators and indoor switchgear for power house.

(ii) Supply of turbines for power house.

(iii) Supply of 14 M.V. transformers for sub-stations.

(iv) Supply of 3 M.V. transformers for power house.

(v) Supply of outdoor structures and switchgear.

(vi) Supply of 110, 66 and 22 K.V. switches for sub-stations.

Specifications were prepared for the following in respect of Kundah Hydro-Electric Scheme :—

(i) Generation plant and switchgear.

(ii) Power transformers and outdoor switchgear.

(iii) Modification of Salem and other sub-stations.

(iv) Transmission lines.

(v) Power transformers at Titruchirappalli and Salem.

Tenders for the supply and erection of Neyveli-Villupuram 110 K.V. line were scrutinised.

A study of the fifth and tenth year load conditions with the Periyar, Neyveli and Kundah Schemes in operation in parallel with the existing Power Houses was made on the net-work analyser at the Indian Institute of Science, Bangalore.

Local purchase orders to the extent of Rs. 4 lakhs were placed during the quarter. Extension schemes numbering 157 and 12 improvement proposals costing Rs. 1·47 crores and Rs. 1·29 lakhs respectively were scrutinised.

B. CIVIL.

Under the Periyar Hydro-Electric Scheme, contract documents for tender for gates and several drawings connected with power house and forebay dam were prepared.

Under the Kundah Hydro-Electric Scheme, specification and drawings were prepared for structural steel work, for power house. Specification for tunnel, surge shaft and pipe tunnel to No. I .P.H. and penstocks to power house was prepared.

Investigation of Schemes.–Kumbar-Amaravathi Hydro-Electric Scheme was under investigation. All the surveys for reservoirs and penstocks I and II were over. Site survey of power house No. 2 and penstock No. I was completed. Drilling operations in the left flank saddle of Kumbar reservoir were progressing.

Design and drawing of Sandynalla dam for Sandynalla Scheme were prepared.

Reconnaissance of the Palar-Perandalur basin was progressing.

Collection and compilation of rainfall and run off particulars of the various basins were continued. The number of rainfall stations, for which data were being collected rose from 523 to 532 at the end of the quarter. Run off statistics were being collected for 33 river flow stations.

Work on installation of nine rainfall stations in Lower Moyar and Kedarihalla lower basins was completed. Work on construction eight of measuring weirs was progressing.

EXHIBITION.

The Department participated in the Seventh Municipal Exhibition held at Tirunelveli from 10th June to 1st July 1956. The stall was largely attended and was very much appreciated by the public. The stall was awarded a gold medal.

Technical Press

I. England-France 200 K.V. under-Link.

A high voltage 150 MW D.C. single cable will link the British supply network with the network of Continental Europe under the 24-mile wide Straits of Dover. By 1960 Great Britain and France, expect to be transferring power as needed in each country.

In 1952, based on the first report of a Joint Technical Committee, a trial length of 132 KV A.C. connection was laid out from the English coast.

Gas-filled pre-impregnated and gas- compression cable types were used. Test reports showed that high voltage D.C. power transmission promised advantages, particularly in controlling load flow.

The French System, with about 50 per cent of hydro-electric plant in its total plant capacity of 16,620 MW, has a considerable amount of spill energy, which cannot be utilised locally. The French 225 KV network can carry energy generated by excess water to the D.C. cable.

The cable is estimated to cost about Rs. 52 millions. Valves on the rectifier and invertor equipment for the project are likely to be of Swedish design made up of four sets of mercury arc rectifiers, each rated 50 KV at 200 amp. joined in series to give 200 KV.

"*Electrical World*"

—October 1956.

2. Worlds Longest Transmission Line Span.

In recent years many high voltage transmission lines have been built across fjords and sognes in West Norway, utilizing a series of long spans. The Sognefjord span, the world's longest is situated in the country of Sogneog Fjordane.

The horizontal distance between the anchor towers on both sides of the fjord varies between 15,800 and 16,000 feet for the four conductors, which have been strung. The elevation of the anchor tower at the south side of the Sogne-fjord is about 1,570 feet, and on the north side about 2,560 feet. The span's lowest point is 223 feet above the top level of the fjord and the sag is thus about 1,870 feet.

The transmission line is 60 KV. but will later be working on 150 KV., which has been catered for in the design.

Four conductors, 164 feet apart, have been strung, the fourth conductor acting as "standby." The total cross-section is about 300 square mm. diameter of conductor about 23 mm. The tension in each conductor is about 15 tons. The conductors were delivered in lengths of 16,700 feet on four drums, the gross weight of each drum being about 14 tons.

To reduce the vibration, eight vibration dampers of the Elgra type are used at each end of the conductors. A tractor was used for the tensioning.

When all the preparatory work was done, an ordinary small cargo ship brought the conductors to the site. All drums were placed in the ship's hold. The laying out and stringing of the conductor was done by means of a drag line and winch, the free end of the conductor being brought up to the anchoring tower on the north side. When the conductor was fastened to the tower, the ship went across the fjord.

On the south shore the conductor was temporarily fastened to a stopping clamp on the beach. Each crossing took about an hour.

The next step was to hoist the end up to the anchoring tower. When the coiled conductor on the beach was fully hoisted, the stopping clamp was released and the stringing started by means of tackles and the tractor winch. The sag was controlled by tachymeter readings.

3. The Spider, Nature's Engineer Extra-ordinary.

Man considers himself a pretty superior being. Yet for millions of years certain of his fellow creatures the Araneida Clan Spiders were doing wonderful feats, like ballooning through the upper atmosphere, diving under water with oxygen tanks, and spinning filaments so fine that even modern science can't duplicate them.

The common spiders are some of the most uncommon creatures ever to evolve on earth. They are true friends of man, in that their entire life is devoted to snaring and devouring insects which might otherwise multiply and desolate the earth.

No climate is too rugged for the clan Araneida. They live on Mount Everest and in caves 2,000 feet below the surface. Pioneers, among creatures leaving the sea to forge new lives on land, they have highly

developed brains capable of memory, and remarkable engineering abilities.

The spider's talent for spinning nets is one of the miracles of nature. With a tensile strength far greater than steel and second only to fused quartz, spider silk can be stretched a fifth of its length before it breaks. A strand that can be seen with the naked eye is usually a cable composed of several tiny threads. A single thread may be only a millionth of an inch thick. All spiders have nipple-like spinnerets located near the end of the abdomen. On each spinneret are a number of minute orifices through which the secretion of the silk glands is expelled.

The most impressive spider web is the orb web. The first line of silk strung up, known as the bridge, is suspended more or less horizontally. Then it drops a plumb line from one end, a lower bridge is built, and a second plumb line fixed on the other end to form an aerial framework. Within the frame the spider strings radii, and at the centre spins a mesh known as the hub. For a safe retreat near the completed orb, she rolls a leaf and spins a silken nest inside and finally she strings a "telegraph" line from the centre of the web to the nest and waits inside her retreat.

When an insect flutters against one of the taut guy lines, which support the web, the line snaps and jerks the victim into the maze. If the catch is heavy, the spider pulls, tightens and spins out, hoisting her prey, nearer and nearer. Amazingly, she has been seen to lift mice and small snakes.

One Eurasian species actually lives under water. While submerged, she resembles a shining globule of quicksilver, for she carries a bubble of air with her. In the spring, she spins a tight, waterproof sheet of silk between the stems of water plants, a few inches below the surface. Then she swims up, flops down on a larger air bubble and carries it under the sheet. After many trips she has made a tiny diving bell which will be her home until autumn.

During the sunny days of spring and autumn, the tiny spiderlings perform the astonishing feat known as "ballooning". They will climb a stem of grass, tilt up their abdomens and spin out lines of silk until a breeze catches their silken chutes and wafts them to new territory.

Most spiderlings, it is estimated float along at heights not over 200 feet, but some have been found as high as 14,000 feet. Baby spiders have descended on the rigging of ships 200 miles from shore.

Spiders are among the most harmless. However, a few spiders, like the Black Widow, have a strong poison, 15 times as potent as that of a rattle-snake, but the supply is so small that it is rarely lethal.

"Readers' Digest"

—February 1957

4. Solar and Wind Power.

Addressing the Bombay Centre of the Institution of Engineers on 11th June, Dr. M. S. Thacker, Director of the Council of Scientific and Industrial Research and Additional Secretary to the Union Ministry of Natural Resources and Scientific Research, indicated that Government "were planning the setting up of technological research centres and organization for directing exploration and exploitation of

solar and wind power in the country". He added that proposals were under consideration for setting up a Wind Power Directorate in the Council and for the study, planning, exploration and exploitation of solar energy in India. Solar and wind power, Dr. Thacker said, were "going to be vital factors in shaping the development of India", where with coal and water resources scattered unevenly, one could "not afford to ignore this potential field of energy".

Dr. Thacker said that attempts were under way to exploit solar energy "on a mass scale", and he added that wind power could also "help in the development of some regions like Rajasthan, Saurashtra, Maharashtra and Madras".

"*F.E.U.*"
—*July* 1956.

5. Rural Electrification.

Discussing the paper on rural electrification presented by Shri V. P. Appadurai and Shri K. R. Radhakrishnan, the Journal of the Institution of Engineers' makes the following suggestions :—

"1. The planning of works in rural areas should be on co-operative lines and a large number of people of those areas should be induced to take active interest in the schemes of rural electrification. This will also help overcome the difficulty of bearing capital cost of installation to some extent. In fact, our ideal in this matter should approach that of Japan rather than of the U.S.A. or any other rich country.

2. Nationalisation of undertakings as is practised now does not seem to be the final solution to the people at large. What is needed is a rise in the standard of work including economical operation of the system. The running of every nationalised undertaking should be controlled on commercial lines and the operational costs must of necessity be cut down as far as possible. The expenditure on administration should be lowered on some such lines as practised in Sweden. A further reduction in running costs can be effected through smaller values of depreciation, achieved by using fewer standbys, the extra risk on this account being eliminated or reduced through better control in work and a general rise in the efficiency of the staff. The tariffs in vogue now are sufficiently low and extra gain in revenue resulting from economical working may be utilised to finance such funds as recommended by the Roorkee Seminar.

3. The growth of electricity in rural areas has been haphazard in the past. A proper planning also suffered for want of standardisation in the country. It may, therefore, be useful to undertake a regular remodelling of old supply lines now through setting up a separate branch of the Department for this purpose.

4. Rural electrification is a problem of extreme importance in a predominantly rural country like India. It is not possible to follow any one country as the ideal. Our highest percentage of electrified villages is 11 per cent in the State of Madras, as against 97·5 per cent in Japan, a country with hardly better resources than ours. In most of the advanced countries of the world the scheme of rural electrification were begun in all earnestness much earlier than in India and we have to make up for the initial lag. It is, therefore, suggested that a separate

administration for rural electrification be constituted in India on the lines of the R.E.A. in the U.S.A. and its counterparts in other countries. In fact, this is more than indicated by the conditions existing in the country and the amount of work still to be done in the field ".

"*F.E.U.*"

—*July* 1956.

6. Future by Slide-rule and not Crystlal-ball.

Britain, like Western Europe, has become power-hungry. Coal is no longer cheap and accessible—and never will be again. Coal reserves—deep beneath the ground—are estimated at 173,900 million tons, of which it is expected to mine 22,000 million tons in the next hundred years, but it will become ever more difficult to mine that amount, despite the fact that the National Coal Board's modernisation and mechanisation expenditure is now approaching £90 millions a year. There is no prospect of the coal industry being able to overtake the rapidly increasing demand. If we cannot increase our power supplies, this country will inevitably lose ground and our living standards will fall. Our future can be predicted by a slide-rule, not a crystal ball.

"*F.E.U.*"

—*July* 1956.

7. Hydro Power Resources of India.

India's "utilisable" hydro-power resources have been roughly estimated at 35 million KW at 60 per cent load factor by the Central Water and Power Commission, which started a country-wide survey on a regional basis in 1953.

This preliminary survey takes into account only resources capable of development on technical and economic considerations in the context of prevailing cost. The assessment is based on readily available data and assumptions made in the case of schemes similarly situated.

The Commission has divided the country into six broad regions : (*a*) the west-flowing rivers of the Western Ghats, (*b*) the East-flowing rivers of Southern India, (*c*) the rivers of Central India, (*d*) the Ganga basin, (*e*) the Brahmaputra basin and (*f*) the Indus basin.

Thus while the problems involved in the development of the west-flowing rivers of the Western Ghats are common—almost all being "high head" schemes, unaffected by conflicting requirements of irrigation, etc., those of the East-flowing rivers of Southern India are different in that over-riding requirements for irrigation have first priority and power development is generally of the "medium head" class. All possibilities of development in each basin are examined. The possible schemes are outlined in complete detail, indicating the location of dam sites with dimensions of dams and reservoir capacities, the type and details of water conductor systems and location of power houses.

Twenty-six such proposals, aggregating to 3·7 million KW at 60 per cent load factor, 43 aggregating to 6·8 million KW at 60 per cent load factor, and 36 aggregating to 3·9 million KW at 60 per cent load factor, have been incorporated in the first three completed reports entitled "East-flowing Rivers of Southern India" and "Rivers of Central India". The

fourth report on the " Ganga basin " indicates a total potential of 12,984 million KW. at 60 per cent load factor of which 7·47 million KW. lies entirely in Nepal. The survey is in progress for the remaining river basins.

When the survey for the entire country is complete in 1958, the " real wealth " of hydro resources, and its distribution and characteristics will then be established, within acceptable limits of accuracy.

It is expected that in the next stage, the hydro-electric survey would extend beyond the present limitation to " preliminary studies ", and cover a long-term, systematic programme of field investigations.

Doubts have been expressed as to the economics of hydro-power in comparison to thermal power. In fact, the cost of production of hydro-power is considerably lower than that of thermal power. The current costs of hydro-power from the various hydro schemes under implementation ranges between 0·2 to 0·3 of an anna per unit in the majority of cases. The cost of thermal generation even from mine-head thermal stations for the largest sizes, is of the order of 0·4 to 0·45 anna per unit at 60 per cent load factor.

" *F.E.U.* "

—*November* 1956.

8. Central Room Lighting.

The architectural flexibility of an overall lighting system known as the "Lumenated Ceiling," recently installed in the central room of Earley Power station, Southern Division, has made possible the provision of an emergency tugsten lighting system to spotlight the control gauges in the event of a power failure in the main generating plant.

Covering an overall area of 48 feet by 25 feet the main luminated ceiling comprises a false ceiling of corrugated translucent vinyl sheet supported in a light-weight frame work, the whole being suspended below a light source of forty-eight 80-watt fluorescent tubes so as to shed diffused, shadow-free illumination on the control panels. The inclusion of emergency lighting has been contrived by dropping the central panels. Adjustable spotlights are set in the two hard board panels running along the borders of the dropped section, the vertical sides of which are fitted with translucent vinyl sheets to provide maximum diffused light to the room.

" *Electricity* "

— *October* 1956.

9. Kundah Power Project.

An agreement between the Governments of India and Canada providing for assistance up to 20 million dollars (Rs. 10 crores) towards the capital cost of Rs. 36 crore Kundah Power Project was signed in New Delhi on December 29, 1956.

The agreement was signed by Sri T. T. Krishnamachari, Union Finance Minister, and Sri M. Baktavatsalam, Minister for Agriculture and Industries, Madras, on behalf of the Government of India, and by the Hon'ble Mr. Paul Martin, Minister of National Health and Welfare of Canada, and His Excellency Mr. Escott Reid, High Commissioner for Canada in India, on behalf of the Government of Canada.

The Canadian contribution will be spent on meeting the charges for the

engineering consultants from Canada and the cost of supplying certain constructional and power plant equipment as well as materials and equipment for the transmission lines of the Project.

The agreemeut also provides that counter-part funds resulting from other measures of Canadian assistance to India under the Colombo Plan be utilised towards the Indian rupee cost of the Project.

The Canadian Government's entire contribution of 7 million dollars for 1956–57 under Colombo Plan is allocated for Kundah Project.

" *Madras Information* "
—*February* 1957.

10. English Electric Generators for Kemano Hydro-Electric Power Station.

Kemano Power Station of the Aluminium Company of Canada has been described as a ' hole ' in the ground 1,135 feet long, 81 feet wide, 134 feet high and located 1,400 feet from the face of the mountain." This ' hole ' will eventually house sixteen generating sets, the ultimate capacity of the station being 2,240,000 h.p.

By means of series of dams, tunnels and channels, a network of lakes and rivers extending over 350 square miles, high up on the eastern side of the rocky Mountains, has been transformed into a reservoir. Two tunnels, each 10 miles long and 25 feet in diameter, carry the water to the turbines in the Kemano Power House almost 2,600 feet below, from which it discharges into the Kemano River on the western side of the mountains. A 300,000 volt transmission line connects the station to the aluminium smelting plant at Kitimat.

The initial stage of the development comprised the installation of three generating sets, which were commissioned in 1954 ; the generator for one of these was manufactured by The English Electric Company and an order for a second generator has since been placed.

The first generator was designed for a rating of 106,000 KVA for 60°C temperature rise of both stator and field windings, with an overload capacity of 122,000 KVA without exceeding 80°C temperature rise. Both these ratings are at a power factor of 0·8 lagging and a terminal voltage of 13,800 volts. The short-circuit ratio was 1·0 and the transient reactance 24·0 per cent.

It was found on tests at site that the turbine and the generator were capable of higher outputs than the designed values, and its rating has therefore been increased to 114,000 KVA for 60°C rise and 132,000 KVA for 80°C rise.

The generator is of the vertical shaft type, with the thrust bearing mounted above the rotor, and is driven by a 4-jet impulse turbine. The normal speed of the turbine is 327 r.p.m. and the designed runaway speed 610 r.p.m. At this speed the peripheral velocity of the rotor is more than 30,000 feet per minute.

The complete stator weighs more than 150 tons. The coils are of the single-turn Roebel bar type, and after insulating were pressed to such a size that they were a tight fit in the slots. Each phase is divided into two equal groups of coils, and both ends of both groups are brought out to terminals to permit the use of split phase protection.

As the coils are spilit at both ends, only the connections between the

coils crossing the splits in the stator, had to be made at site. When completed the stator was transported as a single unit, to its final position.

The rotor body was built up from nine steel plates, each approximately 14 feet in diameter and 11 inches thick. The special turn-table was necessary for machining the flats and tee-slots on the periphery, because of the weight of the hub, approximately 250 tons.

One of the interesting features of the erection of the generator at site was the shrinking of the hub on to the shaft. A hub of this type must be shrunk on with an interference fit sufficient to ensure that it will not float on the shaft at run-away speed. The interference required was ·027 inch, and to insert the shaft safely the bore of the plates had to be expanded by at least ·050 inch, i.e., the plates had to be raised to a temperature of approximately 130°C at the bore. This was accomplished by surrounding the plates with strip heaters and enclosing the whole in an asbestos tent, the heating period required being 17 hours.

The shaft was placed in a hole below the level of the assembly bay, and the plates stacked on when they had been expanded sufficiently the shaft was pulled up into position through the bore. Threading a shaft is always a somewhat delicate operation, which must be carried out accurately and quickly. At Kemano the shaft was successfully inserted in 16 minutes without any trouble.

The poles were built up ofsteellami nations clamped between cast steel endplates by through bolts, which were tightened, while the whole was compressed in a hydraulic press. Each pole is attached to the rotor by a pair of tee-heads. At runaway speed the load on these tee-heads due to the centrifugal force acting on the pole and coil is more than 3,000 tons.

The field coils were formed from copper strip, wound on edge, insulated with asbestos paper between turns and mica between copper and earth, and mounted on sheet steel spools with insulating and metal flanges at each end.

The brakes are designed to bring the set to rest from full speed in 10 minuets.

The thrust bearing is of the standard design employed by the English Electric Company. A forged steel thrust collar is shrunk on the upper end of the shaft,on which it is located axially by a split ring. The lower face of the collar is machined and polished to form the thrust bearing surface, while the vertical face forms the bearing surface for the upper guide bearing.

The interference required for large collars,such as that used for Kemano, which weighs approximately 10 tons make it every difficult for them to be pressed on and removed from the shaft by normal methods, without considerable risk of scoring the mating surface. It was therefore decided to employ the oil injection method for the Kemano collar. With this method the collar is mounted on the tapered seating and oil is injected under high pressure between the mating surfaces. The collar is thereby expanded and can be jacked on or removed from its shaft easily, quickly and with no danger of scoring in only three minutes.

An external pump delivers oil to the bearings from a sump tank via a water-cooled oil cooler. After passing through the bearings, the oil

spills over weirs, fitted in the oil reservoirs. In the event of complete failure of the pumped oil supply, the weirs would maintain the oil level within the reservoirs at the normal running level.

" *The English Electric Journal* "
—*December* 1956.

II. Tit-Bits.

RIVER FLOW USED IN IRRIGATION,

The mighty rivers in India carry a large volume of water. The total annual flow of water is estimated at 1,356 million acre feet. Out of this only 76 million acre feet is being used for irrigation. The rest flows waste into the sea.

We have also 800 million acres of land of which only 277 million acres are cultivated. Of the cultivated land, the area irrigated is only 51 million acres.

ELECTRICITY IN BOMBAY.

" Generation of electricity in Bombay State accounts for one-third of the electricity generated in the country though the population of the State is one-tenth of the total population of India ".

DIRECTION OF CURRENT.

Micchael Faraday in 1820, imagined that current flowed out from the centre of the battery along the connecting wire : and on that basis outlined the right hand rule for determining the magnetic field around the wire. He had but two chances of guessing, one being right, and the other wrong : and be guessed wrong. The only real flow is the flow of electrons and this is opposite to his conception : but the difficulty is now got over by calling the electrons negative. Negative electricity flowing towards you is positive electricity flowing away from you : and Faradays laws still hold good.

THE CENTRAL ELECTRICITY AUTHORITY.

The Authority is the largest individual user of coal in Great Britain, using nearly 40 million tons a year.

On Vesting Day, out of a total of 272,000 farms in the territories of the twelve Area Boards only 85,000 were connected to the public electricity system. In 1956 April, the number connected is over 172,500.

The number of electricity consummers in England and Wales at March 31st, 1956, was 14,146,585. Consumers purchased over 63,000 million units of electricity. The average price received for electricity sold for all purposes was 1,403d per unit.

TURBINE CAPACITIES.

At Grand Coulee, the Francis turbines are rated at 165,000 h.p. at 120 r.p.m. under a head of 330 feet. A bigger unit rated at 187,000 h.p. under a head of 475 feet is installed at Shasta Dam. The latter, however, is not giving its maximum output as it is coupled to an alternator of 75,000 KW capacity. The biggest Kaplan turbine rated at 123,000 h.p. under a head of 81 feet is installed at Dalles.—U.S.A.

The maximum efficiency of Francis turbines has crossed the 94 per cent mark.

The Problem Corner

Problem No. 2.

A plot is in the form of an isosceles triangle of sides 50′, 50′ and 30′. A house is constructed in the shape of a sector of a sphere of diameter 50 feet on a circular base touching the three sides of the plot. Three straight rods are placed with one end at each corner of the plot, leaning on the house, such that they meet at a common point above the house.

Determine geometrically the lengths of the three rods.

A sketch of the plot of ground, and the house thereon, is given on the next page. Solutions to the problem should each tho Editor on or before 15th of October 1957.

The above problem was suggested by Sri S. Raman Assistant Engineer (Electrical).

Social and Personal

1. Sri N. Nuthukumaraswamy, Executive Enginee (Civil) was promoted as Superintending Engineer (Civil) and posted as Superinding Engineer Technical (Civil) on 10th October 1956.

2. Sri L. Ekambram, Superintending Engineer (Distribution), Madras Electricity System, was transferred as Chief Electrical Inspector to Government from 21st November 1956.

3. Sri T. Krishnaswamy, Chief Electrical Inspector to Government, was transferred as Superintending Engineer (Distribution), Madras Electricity System, from 21st November 1956.

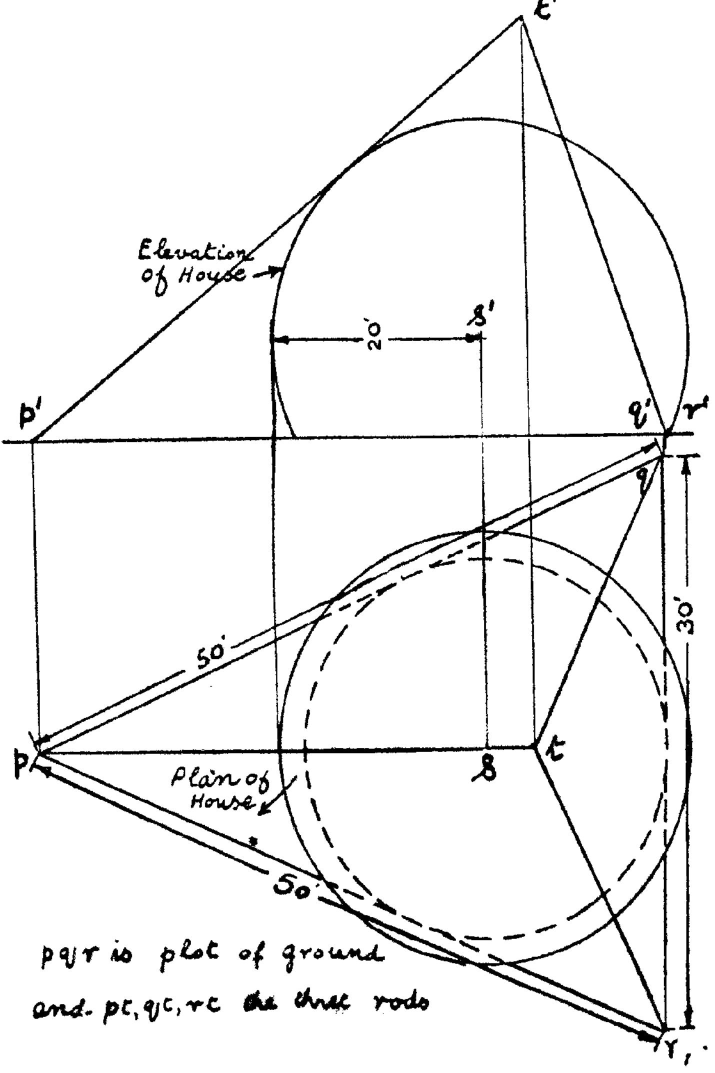
4. The following Engineeres returned from deputation from Germany:—

i. Sri P. A. Raman, Divisional Engineer (Electrical), in October 1956

ii. Sri B. S. Amirthalingam, Assistant Engineer (Electrical), in November 1956.

5. Sri M. P. George, Divisional Engineer (Electrical), Kozhikode, was allotted to Kerala State from 1st November 1956.

6. Sri U. P. Nayak, Divisional Electrical Engineer, Mangalore, was allotted to Mysore State from 1st November 1956.


t'
Elevation of House
20'
s'
p'
q'
r'
q
30'
50'
t
p
s
Plain of House
50'
r
pqr is plot of ground
and pt, qt, rt the three rods

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